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STRATOSPHERIC OZONE DEPLETION AND CHLOROFLUOROCARBONS

JOINT HEARINGS

BEFORE THE

SUBCOMMITTEES ON
ENVIRONMENTAL PROTECTION
AND
HAZARDOUS WASTES AND TOXIC SUBSTANCES
OF THE
COMMITTEE ON
ENVIRONMENT AND PUBLIC WORKS
UNITED STATES SENATE

ONE HUNDREDTH CONGRESS

FIRST SESSION

ON

THE EFFECT OF CHLOROFLUOROCARBONS ON STRATOSPHERIC OZONE, HEALTH EFFECTS OF OZONE DEPLETION, AND SUBSTITUTES FOR OZONE DEPLETING CHEMICALS

MAY 12, 13, AND 14, 1987

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CONTENTS

May 12, 1987

OPENING STATEMENTS

Page

Baucus, Hon. Max, U.S. Senator from the State of Montana 1

Chafee, Hon. John H., U.S. Senator from the State of Rhode Island 3

Durenberger, Hon. Dave, U.S. Senator from the State of Minnesota 32

WITNESSES

Farmer, Dr. Crofton B., Jet Propulsion Laboratory, California Institute of Technology 27

Written statement 118

Fitzpatrick, Dr. Thomas B., chief dermatology service, Massachusetts General Hospital 44

Written statement 146

Hofmann, Dr. David J., professor of physics, University of Wyoming 23

Kripke, Dr. Margaret, Anderson Hospital and Tumor Institute, Houston, TX... 42

Written statement 140

Lerman, Dr. Stanley, professor of ophthalmology, Emory University 46

Written statement 156

Rowland, Dr. F. Sherwood, University of California at Irvine 5

Solomon, Dr. Philip M., State University of New York at Stony Brook 25

Solomon, Susan, National Oceanic and Atmospheric Administration, Boulder, CO 19

Written statement 105

Teramura, Dr. Alan H., Department of Botany, University of Maryland 48

Written statement 243

Tuck, Dr. Adrian, National Oceanic and Atmospheric Administration 28

Written statement 131

Tung, Dr. K.K., Clarkson, University, Postdam, NY 22

Written statement 113

Watson, Dr. Robert T., National Aeronautics and Space Administration 7

Written statement 91

Worrest, Dr. Robert C., Department of General Science, Oregon State University 47

Written statement 228

ADDITIONAL MATERIAL

Chemical Manufacturers Association, statement of 273

United Nations Environment Programme, information entitled, "Nowhere To Hide" 57

May 13, 1987 (p. 279)

OPENING STATEMENTS

Baucus, Hon. Max, U.S. Senator from the State of Montana 279

Breaux, Hon. John B., U.S. Senator from the State of Louisiana 282

Chafee, Hon. John H., U.S. Senator from the State of Rhode Island 280

Symms, Hon. Steve, U.S. Senator from the State of Idaho 301

WITNESSES

Page
Barnett, Richard, Alliance for Responsible CFC Policy 319
  Written statement 423
Blanchard, Elwood P., group vice president for chemicals and pigments, E.I. du Pont De Nemours & Co., Wilmington, DE 294
  Written statement 360
  Letter to Senator Stafford 375
Claussen, Eileen, Director, Office of Program Development, Environmental Protection Agency, Washington, DC 283
  Written statement 333
Doniger, David, Natural Resources Defense Council, Washington, DC 321
  Written statement 432
Fairchild, Phillip D., Oak Ridge National Laboratories, Oak Ridge, TN 286
  Written statement 352
Farber, Hugh, the DOW Chemical Co., Midland, MI 297
  Written statement 394
Jeansonne, Robert L., vice president and general manager diversified products, Kaiser Chemicals, Cleveland, OH 299
  Written statement 402
Lagow, Richard J., Department of Chemistry, University of Texas at Austin 284
  Written statement 343
Mandell, Harry C., Jr., senior vice president, Pennalt Inc., Philadelphia, PA 303
  Written statement 416
Mintzer, Irving, World Resources Institute, Washington, DC 323
  Written statement 444
Traflet, Robert, President, Flourine Products Division, Allied-Signal, Inc., Morristown, NJ 295
  Written statement 384
Turner, Marshall, vice president of manufacturing, Racon, Inc., Wichita, KS 300
  Written statement 412

MAY 14, 1987 (p. 467)

OPENING STATEMENTS

Baucus, Hon. Max, U.S. Senator from the State of Montana 467
Chafee, Hon. John H., U.S. Senator from the State of Rhode Island 468
Stafford, Hon. Robert T., U.S. Senator from the State of Vermont 470
Symms, Hon. Steve, U.S. Senator from the State of Idaho 471

WITNESSES

Benedick, Hon. Richard, Deputy Assistant Secretary for Environment, Health, and Natural Resources, Department of State 475
  Written statement 533
Bowditch, Dr. Fred, vice president, technical affairs, Motor Vehicle Manufacturers Association 504
  Written statement 592
Calio, Hon. Anthony, Under Secretary of Commerce for Oceans and the Atmosphere, Department of Commerce 477
  Written statement 537
Ganser, Neil, President, Neil Ganser, Inc. on behalf of the Society of the Plastics Industry, Inc 510
  Written statement 610
Hipchen, Donald E., vice president, Jim Walter Corp 512
  Written statement 626
Jelin, William, president, N.R.G. Barriers 514
  Written statement 645
Jewell, Carl, manager, fire suppression and detection, Fenwal, Inc 497
Kerckhove, George, group executive and vice president, the Trane Co., on behalf of the Air Conditioning and Refrigeration Institute 499
  Written statement 560
Levy, Michael H., manager, environmental, legislative, and regulatory affairs, Mobil Chemical Co 515
  Written statement 657
Pavek, Richard, president, Tech Spray 517

Page
Pierce, Jon, president, Jon Pierce, Inc., on behalf of Air Conditioning Contractors of America 501
Written statement 584
Taylor, Gary, vice president, Rolf Jensen and Associates, Inc. and Chairman, Technical Committee, National Fire Protection Association 498
Written statement 547
Thomas, Hon. Lee M., Administrator, Environmental Protection Agency 472
Written statement 525

ADDITIONAL MATERIAL

Statements:

Gore, Hon. Albert, Jr., U.S. Senator from the State of Tennessee 522
Dolco Packaging Corp 660
Health Industry Manufacturing Association 663
Ward, Thomas M 675
Stafford, Hon. Robert T., U.S. Senator from the State of Vermont, letter to Hon. Donald Hodel, Secretary of the Department of the Interior 483

STRATOSPHERIC OZONE DEPLETION AND CHLOROFLUOROCARBONS

TUESDAY, MAY 12, 1987

U.S. SENATE, COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS, SUBCOMMITTEES ON ENVIRONMENTAL PROTECTION AND HAZARDOUS WASTES AND TOXIC SUBSTANCES,
Washington, DC.

The Subcommittees met at 9:32 a.m. in room SD–406, Dirksen Senate Office Building, Hon. Max Baucus, Chairman of the Subcommittee on Hazardous Wastes and Toxic Substances, presiding.

Present: Senators Baucus, Reid, Stafford, Chafee, Symms and Durenberger.

OPENING STATEMENT OF HON. MAX BAUCUS, U.S. SENATOR FROM THE STATE OF MONTANA

Senator BAUCUS. Ladies and gentlemen and distinguished witnesses, welcome. This series of hearings will be joint hearings of the Hazardous Wastes and Toxic Substances and the Environmental Protection Subcommittees on the problem of stratospheric ozone depletion. It is a threat to the health and well-being of every living thing on this planet.

Senator Mitchell, who I know has a very deep personal regard for this issue, has responsibilities with the Iran hearings, and therefore, will be unable to be with us this morning. But I want to compliment Senator Mitchell for his very active participation. He would be here were it not for the Iran hearings.

This Committee intends to examine the problem of ozone depletion, particularly stratospheric ozone depletion in three different areas: First, what are the health threats to the global population? Particularly, what new information is available about the effects of increased exposure of ultraviolet radiation because of thinning ultrastratosphere ozone.

Two, what progress are manufacturers of substances, i.e., CFCs, making to find suitable substitutes?

Three, what is our government doing about the problem, and is it enough? Coordinating action on a global scale to address environmental issues like this is difficult. It will require leadership from the United States. Let there be no misunderstanding: This is a man-made problem that requires a man-made solution, and the threat is real.

The sun's most deadly rays are slowly, subtlely being turned up because ozone protection is being reduced. Recent studies have increased our awareness and concern about exposure to the sun and about skin cancers. By destroying the ozone, we are compounding that problem.

Today, we will hear that the rising level of ultraviolet radiation damages the human body's immune system. Critics may charge that we are running around saying, like Chicken Little, "The sky is falling, the sky is falling." Well, it is; it is falling apart.

Every day, chlorofluorocarbons tear up the blanket of protection surrounding our planet. No matter where they are, how they are introduced into the environment, these substances eventually end up in the stratosphere. Once there, they remain for years, chemically killing our ozone protection from the sun's rays. Even if we stopped all emissions of ozone-damaging materials tomorrow, the environmental damage already caused will be felt well into the next century.

Many scientific questions remain unanswered, but the great deal of knowledge is known. There is sufficient evidence to justify immediate action before it is too late. Today, we will hear from a panel of distinguished scientists investigating a large hole in the ozone layer that stretches over Antarctica. Is this a natural phenomenon, or has our industrialized world found our planet's Achilles' heel?

From what we are hearing today, the latter seems to be so. In the spring, the ozone protection over the South Pole will drop by 50 percent; in some places, the protection thins by 90 percent.

We will hear today evidence confirming this as man's doing, not nature's, yet this hole wasn't supposed to exist. Experts said it wouldn't be there, but it is.

That raises a new, more ominous question. Namely, if our models and projections were this far off for Antarctica, how much do we really know about the problem for the United States and the rest of the world, and what can we expect in the future? From the evidence, it is clear that we must turn to science for a solution that science helped create.

We all benefit from the chemicals that damage our ozone, especially those who live and work in air-conditioned comfort during a Washington summer. Yet substitutes for CFCs must be found, and industry must move forcefully to find them.

Solving the problem will be almost as difficult as understanding it. We cannot afford to eliminate CFCs and other substances overnight. Yet we cannot afford to hesitate. We must halt the emission of ozone-destroying materials as soon as possible.

The United States, being the largest producer and consumer of CFCs, should lead the international effort to solve the problem. Last week in Geneva, Mostafa Tolba, Executive Director of the United Nations Environmental Program, called for the elimination of ozone-depleting substances by 20 percent every other year over 10 years. Senator Chafee and I have introduced legislation that would cut emissions by 95 percent over 8 years. Both are good, solid approaches.

Unfortunately, our negotiators in Geneva supported a much weaker proposal: A freeze of emissions at 1986 levels and watered-down standards that would yield no more than a 50 percent cut in emissions. Such a position is, in my opinion, inadequate. Analysis indicates that we need to cut emissions by at least 85 percent to stabilize the ozone layer. A lukewarm response to the ozone problem in the face of compelling evidence as to the health threat it imposes for the United States and the world is unacceptable and irresponsible.

Without strong U.S. leadership, no viable solution exists; no meaningful reduction in ozone destroying materials will be achieved. I am willing to support international efforts and administration initiatives to find a solution, and I am willing to give industry a fair hearing on how we should control these substances.

However, the U.S. must take a strong position. The health of its citizens, indeed, the citizens of the world, is at stake. We must make a significant reduction in ozone emissions, at least 95 percent, and we must start working toward that goal now.

Our responsibilities as a global leader require the U.S. to make the correct decision and to deal with the threat.

We are honored this morning to have Senator Chafee with us who has been working on this issue as long if not longer than any other Senator.

Senator, if you have a statement, we would like to hear it.

OPENING STATEMENT OF HON. JOHN H. CHAFEE, U.S. SENATOR FROM THE STATE OF RHODE ISLAND

Senator **Chafee**. Thank you very much, Mr. Chairman. I want to congratulate you and Senator Mitchell for convening these 3 days of hearings. As you mentioned, Senator Mitchell would be here, but for the fact that he is tied up with the Iran Select Committee hearings of which he is a member.

Both you and he in tandem have pressed ahead, and I am just delighted that we are going to have these 3 days of hearings which are very carefully divided so that we are going to hear from the scientists; we are going to hear from the producers, and really get a thorough handle on this entire problem. These hearings, as I said, are not only timely, but they will address one of the most important global and environmental problems that scientists and policy makers have to deal with; namely, depletion of the earth's protective ozone shield and the need to control the class of chemicals known as CFCs, chlorofluorocarbons.

Someone who had to rely on newspaper headlines to know what was happening in the world might wonder, "Why are we bothering with these hearings? Everything is taken care of."

If you look at page 1 of the New York Times on Friday, May 1st, "31 Nations Agree to Protect Ozone; Accord and Principle Reached to Cut Output of Chemicals."

On page 10 of the New York Times, "U.N. Parlay Agrees to Limit Chemicals that Harm Ozone."

The next Tuesday on page C–1, there was more. "Ozone Agreement is Hailed as First Step in Cooperation."

Based on these headlines, we can all move on to other issues, close shop and figure things are taken care of. If this were true, it would be thrilling. But unfortunately, it is not. There was no agreement in Geneva. There is a piece of paper with two options in terms of ultimate control measures. Even the most stringent of those options, calling for a 50 percent reduction over 9 to 10 years, would allow the amount of chlorine in our atmosphere to grow and deplete the ozone layer. That was a stringent option.

The other option calls for a mere 20 percent reduction in CFCs with the parties agreeing to meet in 4 years to vote on additional reductions. That approach is predicted to result in even greater depletion. How much depletion will depend on a key issue that was discussed, but not resolved, and that is, what substances will be covered by the agreement?

There are other important issues where there are still significant disagreements. I am talking about the international meetings.

What are some of those other issues? What, if any, trade sanctions will apply to entities that fail to sign the agreement or, if they sign the agreement, don't abide by it? What can we do?

Second is how to handle the needs of developing nations without creating a major loophole in the system. These are tough issues, and they must be dealt with before we can judge the success or failure of the international process.

It is highly likely that the proposals developed in Geneva will form the basis for an international agreement. Will that agreement be adequate? I am hopeful, but not optimistic, if you can be both.

To be even minimally adequate, every remaining issue would have to be resolved in the matter that affects the U.S. original negotiating position, broad coverage of chemicals, tough trade sanctions, limited special treatment for developing nations, and reduction with no less than 50 percent in the rest of the world.

As you mentioned, Mr. Chairman, at the opening of the Geneva talks last month, Dr. Tolba, the Executive Director of the U.N. Environmental Program, delivered a statement summarizing our scientific understanding of CFCs and ozone depletion and the need for action. He made several important points that should be reflected in our hearing record and so, Mr. Chairman, I would ask that his statement in Geneva be included in the record of these hearings.

Senator BAUCUS. No objection. (See p. 57.)

Senator CHAFEE. Dr. Tolba would be here with us today if he could, but unfortunately, he could not.

If people succumb to a false sense of accomplishment, that will make our job even harder. You are, Mr. Chairman, certainly to be commended for scheduling these hearings, and I look forward to learning from the distinguished panel of scientists today, tomorrow's discussion of CFC substitutes, as well as the views of the producers and environmental groups that comes tomorrow and on Thursday, a discussion of the Geneva talks and the views of the industries that use CFCs.

So I am delighted that we are under way.

Senator BAUCUS. I thank the Senator.

Our first witnesses are Dr. Rowland and Dr. Watson. Would you please come forward?

Dr. Rowland, why don't you begin?

I would like to note that we have a large number of witnesses today so we will have to hold each witness to five minutes.

STATEMENT OF DR. F. SHERWOOD ROWLAND, UNIVERSITY OF CALIFORNIA AT IRVINE

Dr. ROWLAND. I am sure we will. I am F. Sherwood Rowland, Professor of Chemistry at the University of California at Irvine. Our original paper in 1974 was entitled "Stratospheric Sink for Chlorofluoromethanes—Chlorine Atom Catalysed Destruction of Ozone" and appeared in the Journal Nature with three sentences in the abstract.

> Chlorofluoromethanes are being added to the environment in steadily increasing amounts. These compounds are chemically inert and may remain in the atmosphere for 40-150 years, and concentrations can be expected to reach ten to 30 times present levels. Photodissociation of the chlorofluoromethanes in the stratosphere produces significant amounts of chlorine atoms and leads to destruction of atmospheric ozone.

I think all of those statements are generally accepted in the scientific community now as being descriptions of what happens in the atmosphere.

In 1975, 14 agencies of the U.S. government formed the Task Force on Inadvertent Modification of the stratosphere, and they reported in June of 1975,

> The Task Force has concluded that fluorocarbons released to the environment are a legitimate cause for concern. It also has concluded that unless new scientific evidence is found to remove the cause for concern, it would seem necessary to restrict uses of fluorocarbons 11 and 12 to replacement of fluids in existing refrigeration and air-conditioning equipment and to closed recycled systems or other uses not involving release to the atmosphere.

This means that we have had nearly 12 years of warning that restrictions on fluorocarbons 11 and 12, much more severe than the 95 percent proposed in your legislation, have been suggested by 14 agencies of the Federal Government. So, if we do not have alternatives in hand at the present time, I think that is not because they didn't have 12 years of warning that they might be necessary.

The National Academy of Sciences in 1976 said,

> Selective regulation of CFM uses and releases is almost certain to be necessary at some time and to some degree of completeness. Neither the needed timing nor the needed severity can be reasonably specified today.

That was a warning, again, from the scientific community eleven years ago that indicated that severe restrictions might very well be coming. In the meantime, we have found that the lifetime of the chlorofluorocarbons in the atmosphere is very long. For instance, it is about 75 years for fluorocarbon 11; about 120 years for fluorocarbon 12. Just to let you get a feeling for it, the 120 year lifetime means that 90 percent of what is in the atmosphere now will still be there at the year 2000; 39 percent in the year 2100; 17 percent in the year 2200. It will take of the order of 200 years for the amount of chlorofluorocarbon 12 to drop to only 20 percent of the present level, even if there were no more emitted to the atmosphere, and we are putting in about 400 kilotons per year, 400,000 tons of chlorofluorocarbon 12 going in every year at the present time.

We have known since 1974 that there are two classes of chemicals that are involved: the saturated perhalo chlorofluorocarbons; and the other molecules, which have either a hydrogen atom or a double bond in them.

This, the presence of a hydrogen or a double bond, allows these molecules to be attacked in the lower atmosphere and therefore to be much less threat to ozone depletion.

This means that we have also had 12 years of knowing, 13 years of knowing the direction in which to seek alternatives for the chlorofluorocarbons 11, 12, and 113, that are the most damaging to the atmosphere.

I find it rather ludicrous, as I heard in the House hearings, that it would take another 17 years for us to develop replacements. Thirty years from the time of warning to the time of replacement seems, to me, not to speak very well for the chemical profession in the United States.

I want to say only a little bit more about the Dobson ozone measurements. The Antarctic ozone depletion will be discussed, certainly, by the other members of this panel. The Dobson ozone measurements are the standard technique that has been used around the world since the 1920s, and there are a lot of flaws with these measurements.

Much of the data that is printed in the volumes of the ozone data of the world cannot be trusted to be used in its present form. NASA has a committee that is looking into all of these ozone trends, and, in fact, we have a meeting of one of the subcommittees in Toronto that started about half an hour ago, to which I will go as soon as this testimony is over.

But what we are doing is trying to go over the ozone data that are recorded in these Dobson measurements to see how we can improve the quality so that statistical analyses will be meaningful. In the meantime, my research group has examined the ozone data from several stations that look to be among the better stations. What we have seen in Arosa in Switzerland, with the longest record of ozone measurements anywhere, is that there is a seasonal loss of ozone over Arosa with the heaviest losses in the period from November to March and much lesser losses in the period of the summer.

We have then checked with other stations, and there are two stations of the United States, one in Caribou, Maine and one in Bismarck, North Dakota, that are at the same latitude as that of Arosa in Switzerland, and we have seen a similar pattern; that there is a loss of ozone over Bismarck and over Caribou in the last ten years which corresponds to the pattern seen over Arosa. That is a loss of 5 or 6 percent of ozone in the winter and perhaps only 1 percent in the summer.

At this point, I don't think we can say very much more about the ozone losses from many of the Dobson ozone stations, because we have to validate whether the data that are printed in the books are really accurate data.

I will conclude with this: we are seeing signs of ozone loss in the winter at a number of high latitude stations over North America; we have also seen ozone loss in the upper stratosphere at all latitudes in amounts which are in reasonable agreement with the current theories. Thank you.

Senator BAUCUS. Thank you very much, Dr. Rowland.

Dr. Watson?

STATEMENT OF DR. ROBERT T. WATSON, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. WATSON. Thank you, Mr. Chairman.

In my testimony, I would like to summarize the results of two recent meetings: One, a meeting of theoreticians in Wurzburg, West Germany; and second, what happened at the scientific working group in Geneva last week.

The key conclusion of the Wurzburg meeting was that all of the models that we examined, the one-dimensional models and the two-dimensional models, all agreed when offered a range of emission scenarios. In other words, all the results were quite consistent, within approximately 50 percent.

This got around the basic issue of whether American modelers had one result and European modelers had a different result. We disproved that, and therefore, people in the European commission could no longer say there is a different view in science between Europeans and Americans.

We then did further calculations to see how well we could protect the ozone layer given different types of control strategies. We tried one very academic exercise, and that was a true global freeze of all chlorines and all bromine compounds. It is academic. It would be very hard, academically, to enforce. Even a true global freeze would leave a 1 to 2 percent ozone depletion globally.

Dr. Tolba is going to try to resolve that at the Council. If he doesn't resolve it, it could lead to a complete removal in the negotiations.

Last week, when I chaired the technical working group in Geneva, we tried to give some pieces of advice to the policy-makers and pieces of information they should remember. The simple motherhood statement is that we should remember that ozone, the column content, the vertical latitude and distribution totally respond to total chlorine and total bromine; it doesn't matter whether it is chlorofluorocarbon 11, chlorofluorocarbon 12; whether it comes from a refrigerator or whether it comes from an aerosol can.

What we pointed out is that any regulations which only control 11 and 12, which is what some countries want to do, and then allow substitution for other fluorocarbons, like 114 and 115, would not provide protection for the ozone layer. Any substitution of 11, 12 or 113 by other long-lived gases, such as 114 and 115, would clearly not protect ozone.

We have to make sure that that loophole does not occur. What we tried to point out also to the policy-makers was: Do not consider just the global ozone content. People often look at this and say, "If we have a control strategy, to what extent will global ozone change?" We must look and see if there are changes in the vertical distribution. We may not fully understand the changes in ozone at 40 kilometers. It would clearly lead to large changes in temperature and potential changes in circulation. The fact that we do not understand what the ramifications are does not mean we should not be concerned. So we tried to point that out.

When thinking of substitutes, we pointed out that fluorocarbons such as fluorocarbons 22 and 123 that do contain a hydrogen atom have a very short atmosphere lifetime, maybe 120th or so of those of the long-lived gases like 11 and 12, and so for the equal volume you emit into the atmosphere, only 120th will get into the stratosphere.

Therefore, almost by default, you have in essense, protection of the ozone that amounts to 95 percent. I do think we do need to look at substitutes such as 22 and 123. However, when thinking about substitutes, one most clearly remember that all nearly all fluorocarbons, if we go in that direction, substitutes, have an additional atmospheric property.

That is to say, we have infrared absorption. They are greenhouse gases. In simply substituting one fluorocarbon for another, we must remember not only to look at the potential by which they can deplete the ozone, but we also have to see if they have the potential to cause the greenhouse warming. I think that is something that is extremely important.

After that, fundamentally, there are some other motherhood statements about scientific research. I think we should remember that fluorocarbons are only the first of the issues. We should remember methane, carbon dioxide and carbon monoxide increase this problem and at some point, scientists and policy-makers have to grapple with these issues, as well.

In my testimony, I do discuss the process by which NASA is reviewing all the ground-based satellite data. Dr. Rowland plays a key role in this. He chairs one of the most important subgroups, and I think there is valuable information there.

The ozone hole you will hear about in the future panel. I think suffice it to say that the U.S. government and industry have gotten together to fund the program that is being very strongly campaigned in 1987. It will take ground-based data, satellite data, aircraft data, and the goals and objectives of this are to refine even further whether or not human activity is causing the ozone hole or whether it is a quirk of nature.

The project scientist, as you know, will discuss this in greater detail. Thank you, Mr. Chairman.

Senator BAUCUS. Thank you, Dr. Watson. What I would like to determine, the best I can, is what is agreed to within the scientific community as to the degree to which chlorofluorocarbons do cause ozone depletion, and therefore, greater ultraviolet radiation; and second, what is not agreed to. That is, what is significant and relevant, and what has yet to be determined? What is agreed to?

Dr. Watson, you said the models all agree. The question is: What do the models all include? Second, where is the disagreement, and where do we have to develop some records? In answering the question, to which degree is the chlorofluorocarbons the main culprit and to which degree is the Halons the culprit?

Dr. WATSON. There is always some debate as to how accurate the atmospheric models are. However, they tend to describe today's atmosphere relatively well. We try to determine today's atmosphere. We do field measurements to observe the chemical composition and physical structure of the atmosphere and to a best approximation, they do a fairly credible job.

Therefore, while there is some limit to our confidence in these models, they clearly represent a good effort to move forward in the future. One thing I think the scientific community strongly agrees on is that if you put chlorine into the atmosphere, it will destroy ozone at 40 kilometers.

Whether the column will change the magnitude and the timing is a little more complex. We need to know more about the scenario of the chlorine and the methane. Even in the laboratory, we have found no mechanism by which if you add chlorine to an oxygen ozone system, you can produce ozone. That is different from the nitrogen methane system, where you can actually produce ozone. What I think the scientific community agrees on is that if you put chlorine in the atmosphere, it will lead to the destruction of the ozone, or bromine.

We can't very easily come up with a mechanism by which ozone is produced by the addition of chlorine into the atmosphere.

Dr. **Rowland**. I think probably the area of greatest uncertainty is the forward projection of calculations of ozone depletion. I think the reason for this uncertainty is that we don't really understand that well what is going on in the lower stratosphere in the temperate and tropical zones. This means that probably there is some carryover, I think, from the observations in the Antarctic.

The Antarctic is clearly a very specific case, but the heterogeneous reactions that are occurring there may occur on stratospheric particles over the temperate and tropic zones.

If they do, and I don't think we know how to put those measurements into the models at this particular time, then it could very seriously affect the long range calculations of ozone depletion, and it would affect them in a direction that the depletion would be greater than is calculated without them.

But I don't think we know how to put those reactions in, and we will probably need measurements in the lower stratosphere over the temperate and tropical zones in order to get even a feeling for how to put those into the model. So at the present, I don't trust any of the long-range predictions, because I don't think the model is yet tuned carefully to the present atmosphere.

Senator **Baucus**. I wonder if we could refine that a little more, though. Give me an outside parameter as a low and a high. I assume there is some agreement within the scientific community as to projecting how much the ozone will be depleted at present growth rates of chlorofluorocarbon production and assumption.

I wonder if you could narrow that a little. I assume there is still some agreement within the scientific community. One way to get at that is what is the most responsible low estimate, say, by the year 2020, and what is the most responsible high estimate?

Dr. **Rowland**. I am not aware of any model that has put in or tried to put in the equivalent of what is going on in the Antarctic with sufficient success that we can put very much limitation on what the outer limits are in the future.

Senator **Baucus**. Dr. Watson?

Dr. **Watson**. I would agree with that statement. I think what Dr. Rowland is really saying is that the key issue here is if, indeed, it is a chemical mechanism that is destroying ozone in the Antarctic, that that is still verified, in my opinion, but if it is and it is a heterogeneous process, and if these heterogeneous processes are occurring in other latitudes, in all probability, all that will lead to is an increase in our reduction of ozone depletion.

It will not reduce the level by which ozone is depleted. In other words, it is a lower case. As I said earlier, even a true global freeze on fluorocarbons will still lead, in these calculations, to, say, a 2 percent reduction in ozone over the next 50 years. That even masks the real issues of 20 to 30 percent reductions at 40 kilometers and 3 to 5 percent reductions at 60 degrees north.

If these processes are postulated to occur in Antarctic surfaces, will that occur in other latitudes? In my opinion, it could only lead to larger depletions, not lower.

Senator BAUCUS. You say 20 to 30 percent reductions at any latitudes.

Dr. WATSON. Twenty to 30 percent reductions at high altitudes.

Senator BAUCUS. Excuse me, altitudes. By when?

Dr. WATSON. The year 2050. It is a monotonic process. So it will be 10 to 20 percent in the next, say, 30 years, out 20 to 30 percent in 50 years. Actually, a part of my testimony which I have attached to my official testimony are some calculations and figures that you can look at at your leisure.

Senator BAUCUS. Would you or Dr. Watson tell us a little more about some of the problems of excluding developing countries? Expand on that a little bit. Tell us your thoughts about that.

Dr. WATSON. It is often very simple. If, indeed, the whole of the developed world was to have regulations on fluorocarbons, would it be a freeze or a 95 percent phase-out. But if the developing countries were still to rely on fluorocarbons, given they are relatively cheap substances, any growth anywhere in the world would lead to an increased Halogen loading, therefore to an increased depletion of ozone. Therefore, if we had a strategy which by we had severe constraints in the developing countries, but we do not have any constraints in the developing world, and if the growth is anywhere close to what we predict by the USEPA, that would show quite large increases and therefore, ozone depletion. EPA predicted a 3 to 5 percent growth in fluorocarbons 11 and 12 in the next 30 to 35 years.

Senator BAUCUS. My time is up.

I note the former Chairman of the Full Committee, Senator Stafford, has arrived. The Senator is very, very active in clean air issues generally, also in ozone depletion.

Senator, do you have a statement you would like to make?

Senator STAFFORD. Thank you, Mr. Chairman. I have no opening statement. I am sorry I wasn't able to get here in time to hear the opening statements of the witnesses, but I do have some questions when my turn comes up.

Senator BAUCUS. Senator Chafee?

Senator CHAFEE. Thank you, Mr. Chairman.

Dr. Watson, on page 2 of your testimony, the second point you raise, it seems to me, is a critical one. As you may know, the industry representatives contend that nothing more than a freeze on CFC production is needed at this time. Yet you speak of there being some ozone depletion even with a true global freeze. I have a couple of questions on that subject.

First, when talking about a true global freeze, you assume that every nation joins the protocol, nobody is left out, and there is no special allowance for developing nations; is that correct?

Dr. WATSON. Yes. That is why it is an academic calculation; that is exactly correct.

Senator CHAFEE. Second, is it your understanding that when the nations that were negotiating in Geneva talked about a freeze, were they considering a true global freeze?

Dr. WATSON. No. They were always talking about special exclusion for the developing countries.

Senator CHAFEE. Therefore, under a realistic global freeze on CFC production, the level of ozone depletion can be expected to be even higher than what you have projected?

Dr. WATSON. Correct.

Senator CHAFEE. In that same paragraph, you raise two other important points that perhaps are worthy of being highlighted. First you say that even when total ozone depletion is small, there will be a redistribution of ozone in the vertical column.

What is the meaning of that?

Dr. WATSON. In these calculations, we not only assume that fluorocarbons are going to be admitted into the atmosphere, but the amount of methane and carbon dioxide are also increasing. What happens in these calculations is you predict an increase of ozone near the ground, predominantly using methane, and a decrease of ozone nearly 40 kilometers due to fluorocarbons.

Ozone produced near the ground is not merely a fluorocarbon problem; it is a methane problem. If there were, the increase in ozone is detrimental. It is an incremental greenhouse gas. It could add to the global warming issue. It is a toxic gas. Ozone increases near the ground level are not to the best advantages of society.

The decrease of ozone at 40 kilometers will clearly lead to a cooling of the stratosphere, anywhere from 5 to 20 degrees, depending on the magnitude of the ozone depletion, that could lead to changes in the circulation pattern, and the scientific community, at this moment, doesn't fully understand the ramifications of a change in temperature certification on, say, weather surfaces.

However, it is something we should be concerned about. It would mean a significant change in a part of our environment.

Senator CHAFEE. I think that is important, because the direction, it seems to me, of our concerns have to be not only for health of our people, but these climatic changes that could well come about; the effects on our water; the effects on our crops; all kinds of issues other than straight health concerns.

The second issue has to do with the meaning of global averages and the fact that depletion at higher latitudes, like North America and northern Europe, will be greater than the global average. You just answered that in connection with the question of Senator Baucus.

What is the extent of the variation? For example, if the global average is 5 percent depletion, what can we expect over our heads? Can you quantify that?

Dr. WATSON. Yes. It depends on the distance. There is a range of the results. The one result that is robust and very consistent between all models is they all show least depletion at the equator; most depletion at the poles. That is robust; somewhere about a 2-to-1 variation of equator-to-pole. Others get 98 or 90 or 10 to 1. There is a range of 2 to 1 to 10 to 1 from equator to the pole. On average, 40 degrees north, which is roughly here, tends to be consistent with the global average.

It is when you get to 60 degrees north; then you often have depletions, let's say, one and a half to twice the global average. When you get to 90 degrees north, it is significantly larger. So the global average tends to represent, and for no necessary physical reason, tends to represent somewhere between 30 and 40 degrees north. It depends on exactly which scenario you run and exactly which model you look at.

Senator CHAFEE. Okay. On page 22 of the Wurzburg report, if I can read these charts correctly, cases 6, 7 and 8 represent the most stringent option that is on the table at Geneva now, essentially, a 50 percent reduction in production of all the chemicals that we are discussing.

Are the scientists projecting that such an agreement will result in global average depletions of about 5 percent by the year 2050 and 9 to 10 percent by the year 2060?

Dr. WATSON. Yes. The uncertainty in that calculation is the assumptions of growth in the developing countries. We took the USEPA gross scenarios for scientists, not economists, so we had to take that at face value. It was one area where I know industry strongly disagrees. They don't believe that the developing countries will grow that 3 to 5 percent per year. They also don't believe the current distributions in our calculations and how much is used in developing countries.

If the USEPA projections are correct in the growth of fluorocarbons in developing countries, those projections should show that even with a 50 percent cutback in the developed world, you would still get at least a 5 percent reduction in ozone by the year 2050.

Senator CHAFEE. Dr. Rowland, when you were here last time, let me see if I am correct in this, you said that what we ought to do is, in automobile air-conditioners, move from CFC 11 and 12 to CFC 22, if I recall correctly. Is that your suggestion?

Dr. ROWLAND. CFC 22 is a prototype of the kind of substitution that we should be seeking, because 22 has a hydrogen atom in it and can be attacked in the lower atmosphere. Therefore, it presents much less of a threat to the stratosphere.

But there are many other compounds in the same category as 22: Fluorocarbon 123, fluorocarbon 134-A, and the specific choice for the specific use would probably depend on two things: One is the availability of the compound and the other is the suitability for the particular device; that is, for which the substitution is used, for which the substitute is sought.

Senator CHAFEE. What troubles me is that we are liable to take that. If we take 22, we are liable to have that as part of the problem rather than part of the solution, because if 22 has an ozone depletion potential which is, only, say, 120th of 11 and 12, the question is, can we afford to leave 22 unregulated and let it grow?

Because if it grows to 20 or 40 times the current level, then we will have the same problem right over again: A smaller, lower damage rate that you would have with 22, but since you have got more of it, the result is just the same as the present amounts of 12.

Dr. ROWLAND. I agree that in the long run, 22 and all of the substitutes which contain chlorine are suspect, because it is the delivery of chlorine to the stratosphere that is the problem.

The long-range solution probably goes toward molecules like 134-A, which is a hydrofluorocarbon, but not a chlorofluorocarbon. The presence of the hydrogen in it allows it to be attacked in the lower atmosphere so it won't accumulate and be a serious greenhouse problem.

The absence of any chlorine in it means that there is essentially no stratospheric ozone problem.

The search for compounds which do not contain chlorine is certainly the long-range direction to go in. In the short run, short run meaning probably the next 20 years or so, I think every molecule of fluorocarbon 22 you put in instead of a molecule of fluorocarbon 12 leaves us well ahead as far as the problem of delivering chlorine to the stratosphere. So it is a short-term solution pending the discovery of molecules which can be produced in large quantities that don't have either greenhouse or stratospheric ozone problems.

Senator CHAFEE. Thank you. My time is up. Thank you.

Senator BAUCUS. Thank you, Senator.

I notice that Senator Reid from Nevada has arrived, a very able member of this committee.

Senator, do you have a statement at this time?

Senator REID. No, I don't, Mr. Chairman. I do want to say that I am very anxious to listen to the testimony of these witnesses. We had hearings of a similar nature when I served on the Science and Technology Committee in the House, and the committee staff and the chairman is to be commended for calling these hearings.

Senator BAUCUS. Thank you.

Senator Stafford?

Senator STAFFORD. Thank you, Mr. Chairman.

I do have some questions I would like to address first to you, Dr. Rowland, and then to you, Dr. Watson, for comment, also.

My first question is this: In your judgment, Dr. Rowland, does the analysis of actual measurements indicate that some portions of the stratospheric ozone layer have been depleted? By depleted, I mean that the concentrations of ozone are lower than they would be in the absence of human activity.

Dr. ROWLAND. My answer to that would be yes. The indications are that we have ozone loss in the 40 kilometer altitude range at the level at which chlorine is predicted to have its major effect over the tropical and temperate zones, and there is certainly evidence of massive ozone loss over the Antarctic. I believe that the Antarctic ozone loss is primarily caused by the fact that there is much more chlorine there than there was in the 1950s and 1960s.

Senator STAFFORD. Dr. Watson?

Dr. WATSON. I would agree completely with the statement about 40 kilometers. Both satellite and ground-based stations appear to show a decrease in ozone near 40 kilometers consistent with the fluorocarbon theory. There is no question ozone is decreased drastically in the Antarctic region. In my opinion, it is still premature to conclude it is human activity, i.e., fluorocarbons, even though the evidence does suggest that chlorine is highly disturbed there.

Senator STAFFORD. Next question, Dr. Rowland.

If it is your personal judgment that there has been depletion of some portions of the stratospheric ozone layer, do you believe there is a consensus within the scientific community to the same effect?

Dr. ROWLAND. I think you just heard from Bob Watson a representation of the scientific community consensus. I don't think I can speak for the consensus very well.

Senator STAFFORD. I am asking for your opinion about it.

Dr. ROWLAND. I think there is agreement that there is a loss at 40 kilometers. I don't believe there is overwhelming consensus on the chlorine effect in the Antarctic, but I think that the evidence is very strong in that direction.

Senator STAFFORD. What would your comment be, Dr. Watson?

Dr. WATSON. I would agree with the answer given by Dr. Rowland.

Senator STAFFORD. All right. If there is depletion of the ozone layer, proven by analysis of actual measurements, is it your individual and personal judgment, Dr. Rowland, that emissions of CFCs and Halons are more likely than not to be the cause?

Dr. ROWLAND. I would certainly answer yes to that, because "are more likely than not" is not a very strong statement. I would go much further than you have gone.

Senator STAFFORD. That is——

Dr. ROWLAND. I think it is clear that CFCs are causing destruction of ozone.

Dr. WATSON. I think that 40 kilometers, the evidence does seem to suggest that it is quite likely that it is fluorocarbons. I think the campaign you will hear later this year will make a case for or against fluorocarbons in the Antarctic. I think the answer is 6 or 8 months.

Senator STAFFORD. Dr. Rowland, do you agree that the so-called ozone hole, originally over Antarctica, but now having spread to the southerly regions of South America, was not predicted by the scientific community?

Dr. ROWLAND. Yes.

Dr. WATSON. No question at all.

Senator STAFFORD. Dr. Rowland, can you state with confidence and certainty that ozone depletions will remain within the upper bounds predicted by the Rowland-Molina theory and that there is no possibility within the realm of reality of a runaway reaction of some sort in the atmosphere?

Dr. ROWLAND. No, I can't agree that we have that much knowledge that we know exactly what will happen. I would bring in the reaction of hydrogen chloride and chlorine nitrate, which I think is going on in the Antarctic. That is a reaction that involves two reservoirs of chlorine interacting with each other and putting the chlorine into a form that becomes available for depletion of ozone.

So that is a reaction of one chlorine with another, which makes, as you increase the total amount of chlorine, the likelihood of ozone depletion become much greater.

This reaction and others are not in the atmospheric models yet. I don't think we know how to do it at this point. I am not sure that we know what to put in as upper bound unitl we can satisfactorily model these reactions, too.

Senator STAFFORD. Thank you.

Dr. Watson?

Dr. WATSON. I actually agree with the answers of Dr. Rowland.

Senator STAFFORD. I thank you both. I will comment in closing that I made a speech on atmospheric contamination yesterday including observations of a layperson based on scientific testimony on this subject, and I am glad I haven't heard anything yet that would disprove what I said.

Senator BAUCUS. Thank you, Senator.

Senator Reid?

Senator REID. No questions, thank you.

Senator BAUCUS. I have one question about the greenhouse effect of CFCs. A lot of the discussion here is based upon CFCs causing depletion with chlorine causing depletion of ozone in the stratosphere.

I wonder if both of you could address the degree to which CFC production and assumption and emission also is a greenhouse gas, agree as to whether that is a problem?

Dr. ROWLAND. All of the calculations on the greenhouse gases show that the chlorofluorocarbons 11 and 12 are appreciable contributors. More or less by chance, their infrared absorptions come in regions which are not blanketed by carbon dioxide, ozone and water, and as a result, they fall in transparent infrared regions of the atmosphere. They are very effective in holding in infrared radiation, the basis of the greenhouse effect, far more effective than additional molecules of carbon dioxide, for example.

The fluorocarbons are between 10,000 and 20,000 times more effective molecule-for-molecule than carbon dioxide. This is enough to put them into the same league with carbon dioxide, the main contributor to greenhouse effect. But both fluorocarbons 11 and 12 are important contributors.

Dr. WATSON. Yes. To quantify that further, if fluorocarbon 11 and 12 were to increase at, say, 3 percent per year for the next 20 or 30 years, by about the mid-2020s, they would actually contribute to about 20 percent of the total effect of greenhouse, about half the magnitude of CO_2. CO_2 would contribute 50 percent; fluorocarbons 25 percent; methane and nitrous oxide, the other 25 percent.

If we were to freeze fluorocarbons 11 and 12 at today's level, then by the mid-2020s, they would contribute 10 percent. Obviously, if we had a 95 percent phase-out, they would contribute only about 1 percent. One can see they are significant contributors in the quantitative sense.

Senator BAUCUS. Thank you.

Senator Chafee?

Senator CHAFEE. Thank you, Mr. Chairman.

I have a question for Dr. Rowland, and it is as follows: I have seen figures suggesting that chlorine content in the atmosphere today is about three parts per billion and that a production freeze at the 1980 level would raise that to eight parts per billion in about 50 years.

Do you agree with me so far?

Dr. ROWLAND. I put three and a half, or a little bit more, parts per billion as the level in the northern hemisphere at the present time, increasing at a rate of a little bit more than one part per billion per decade, so that yes, in 50 years or so, we would certainly be at around eight.

Senator **Chafee**. If we decide that we don't want to go above three parts per billion——

Dr. **Rowland**. It is too late.

Senator **Chafee**. All right, three and a half parts per billion. Give me four.

It has been suggested that we have to reduce CFC production by 85 and 95 percent. In other words, the chlorine does have a life expectancy. It doesn't last forever, does it?

Dr. **Rowland**. Well, it doesn't last forever, but as I indicated before, 20 percent of the fluorocarbon 12 will still be here 200 years from now. So that it lasts, on a time scale you and I can expect, it lasts forever.

Senator **Chafee**. In other words, if we are going to limit the increase of chlorine to three and a half parts per billion then we have got to take very drastic action.

Dr. **Rowland**. An 85 or 90 percent reduction would be the amount that we would need.

Senator **Chafee**. Do you think that the proposals in Geneva now will adequately protect the environment?

Dr. **Rowland**. No.

Senator **Chafee**. What do you say, Dr. Watson, to that?

Dr. **Watson**. It is clearly a step in the right direction. I think that would be a statement. As I have said earlier, I am very concerned about this whole exclusion for the developing countries. So even if there were a 50 percent cutback in the developed world, even if there is an agreement, which would be a significant step, this exclusion for the developing countries would mean large growth in chlorine and, therefore, large ozone depletions.

So in its current formulation, one would still expect to see significant ozone depletion.

Senator **Chafee**. What is the global significance of what they are discovering in the Antarctic now, Dr. Watson?

Dr. **Watson**. I really don't think we know that yet. I do agree, and you will hear later in another panel, that the chlorine count is highly disturbed. Therefore, the probability of chlorine destroying ozone in Antarctica is reasonably high.

That could be perverse, though, and that is why I think we should wait for 6 months to really understand it. As chlorine could be very disturbed, that could be a naturally dynamic phenomenon. I think the jury is still out. I think until we understand how and why the chlorine is destroying ozone in Antarctica, we truly can't say what the global ramifications are.

If it is, indeed, a heterogeneous mechanism, as proposed by people like Dr. Rowland and Susan Solomon and others, then indeed, it may well have some global ramifications. If so, the ozone depletions would be higher than currently predicted.

Senator **Chafee**. What do you think is the global significance of the data coming out of the Antarctic, Dr. Rowland?

Dr. **Rowland**. I think, as you will hear, Dave Hofmann's measurements clearly show that there is a lot of heterogeneous activity going on down in Antarctica, and the other measurements that you will hear from the Antarctic people, are, to me, very consistent with heterogeneous chemistry plus chlorine chains in the Antarctic. Heterogeneous chemistry is indicated there.

Senator **Baucus**. Dr. Rowland, could you explain what heterogeneous chemistry means?

Dr. **Rowland**. Sure. All of the models that have been used up to this time assume that molecules are in a gaseous phase, free to move about and collide independently in that fashion.

Heterogeneous chemistry simply means that some of the reactions take place on surfaces, and surface reactions are very important in chemistry. They are the basis for 'cat cracking', for instance, in making usable gasoline out of the heavy fractions of petroleum. And the problem with heterogeneous chemistry is that the surfaces are very hard to duplicate.

In the Antarctic, we know relatively little about those surfaces, as we know relatively little about the surfaces of the stratospheric particles that are available over the temperate and tropic regions. For that reason, it is going to be very hard to transfer estimates of heterogeneous chemistry in the Antarctic to estimates of what will happen over the other latitudes.

Senator **Baucus**. I am sorry. You say surface; what surfaces are you talking about?

Dr. **Rowland**. In the Antarctic, the atmosphere gets very cold, and the coldness causes the production of polar stratospheric clouds. These clouds probably have a lot of water ice in them, but they their exact composition is not really known.

Senator **Baucus**. It is cold surfaces.

Dr. **Rowland**. It is the surfaces of those clouds, which occur in the lower stratosphere, and which are easily seen down in Antarctrica and which we think are the basis for some unusual chemistry.

The problem is that this is unusual chemistry, which then allows chlorine to be released by the first sunlight of the Antarctic spring, and then the chlorine chains run wild for a month or so. That is my interpretation of what is happening down there.

But the question is: How do you transfer this knowledge to the other latitudes? That is a very difficult problem which I think is only going to be solved by actual experiments in the temperate and tropic stratosphere.

Senator **Baucus**. I am sorry, Senator. I interrupted you.

Senator **Chafee**. I just have one quick question of Dr. Watson. That is, as I understand what you are saying, Dr. Watson, it is that, Let's wait, you said, 6 months; but let's wait and analyze the Antarctica data a little further; is that correct?

Dr. **Watson**. I think that is clearly a policy decision, not a scientific decision. I believe you will hear lots of evidence suggesting that chlorine is highly perturbed. Therefore, in many people's minds, it is highly probable that the Antarctic ozone loss loss is due to fluorocarbons.

In my opinion, we will increase our level of knowledge by almost an order of magnitude, this year, between August and October by using aircraft, satellites and ground-based stations. I believe in that case, the scientific community could say to people like yourself with much greater confidence: Is chlorine destroying ozone in Antarctica and is it having global application? It is still clearly not a scientific decision, it is a policy decision, and I recommend waiting 6 months.

Senator **Chafee**. But despite that situation, you would recommend that we do something about curbing the CFCs now; is that correct?

Dr. **Watson**. Oh, absolutely. I believe personally that policies should be made on the probability of chlorine destroying ozone globally, which we have discussed at great length here, and which both Dr. Rowland and myself have said, we in the scientific community, we believe the chlorine depots are destroying ozone globally.

I believe we have enough evidence, enough scientific knowledge to move ahead with regulations, nationally or internationally, today. In my opinion, if the Antarctic ozone depletion is due to fluorocarbons, it would probably mean, especially if it had global ramifications, that we would have to set, potentially, a schedule for the sort of legislation that you and Senator Baucus have proposed.

Senator **Baucus**. What is the probability that Antarctic ozone depletion is caused by chemical reactions to chlorine? What is the percent of probability, in your judgment, that it is natural-based and what probability is it sun spots? Based upon what you know today, give me a rough guess.

Dr. **Watson**. Close to zero on sun spots; less than 10 percent likely on sun spots. By looking at the simple evidence, 80 percent probability of it being the chlorine hypothesis; 20 percent probability being dynamic. If I had to bet on it, I would actually bet on nature being perverse and not having it be as simple as it looks.

The atmosphere is very complicated. Given that I believe we will have an extremely excellent program in six months, it is not a simple bet. The evidence seems to lead you down the path of saying it is chlorine. I am not quite sure I want to go down that path just yet.

Dr. **Rowland**. I will take 100 for chlorine, zero for sun spots, zero for dynamics.

Senator **Baucus**. Someone is decisive.

Dr. **Rowland**. I also think that we will find out a very large amount of information by the expedition to the Antarctic. As a scientist, I am very interested in that. From the standpoint of regulation, I think what we are trying to find out is how the chlorine is removing the ozone there, not whether it is.

Senator **Baucus**. Thank you.

Senator Reid, do you have a question?

Senator **Reid**. In so many of the areas that we deal with, Superfund, different research on diseases, the typical statement we hear from people like the two of you is that there is not enough money to adequately study the situation.

I would like to hear something from either of you. I came, and although I didn't hear all of your testimony, in this instance, when we are talking about the ozone depletion, is there enough scientific research being done on that at the present time, including this expedition that is going to take place in the near future?

Dr. **Rowland**. That is a difficult question in the sense that Bob controls most of the money that is available and I get my money from Bob.

Senator **Baucus**. Now is your chance.

Dr. **Rowland**. My impression is that we are not grossly underfunded in that sense. I think we can always use more money for scientific research in this particular area, but most of the people that are doing it are funded reasonably well.

This is a crash program to send two airplanes down to the tip of South America and operate there for 6 or 7 weeks, and I am sure that is putting a serious strain on the amount of money that was appropriated before they knew that that would be what they would want to do.

So that I think a 50 percent increase in the budget that Bob has available would be gratefully received by the atmospheric community. With a factor of 10 increase, we would probably have difficulty knowing what to do.

Senator **Reid**. Would you agree, Dr. Watson?

Dr. **Watson**. I think that is a reasonable assessment. In general, stratospheric ozone research has been very well funded by the U.S. government, at least understanding the chemistry.

Understanding the effects of ozone depletion is grossly underfunded, not only in the United States, but abroad. Indeed, this ozone campaign has stretched our budget. It is probably costing an additional $5 million at the $20 million program. So to reprogram 25 percent of one's budget within a fiscal year clearly puts constraints on the other parts of the program.

I am much more concerned, personally, by other elements in earth sciences that are not adequately funded. We have to understand that the atmospheric, ocean and land surfaces truly interact on the climate ozone issues. Then I believe there are many areas of earth sciences that do require additional funding.

Senator **Baucus**. Thank you very much, gentlemen. I appreciate your testimony.

Our next panel will look a little more closely at the Antarctic situation. Our next panel will include Dr. Susan Solomon from Boulder, Colorado; Dr. Tung, Potsdam, New York; Dr. David Hofmann from Laramie, Wyoming; Dr. Philip Solomon, Stony Brook; Dr. Crofton Farmer from Pasadena, California and Dr. Adrian Tuck, also from Boulder, Colorado.

Dr. Solomon, why don't you begin?

STATEMENT OF SUSAN SOLOMON, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, BOULDER, CO

Dr. **Solomon**. Mr. Chairman, members of the Subcommittee, I appreciate the opportunity to discuss research on the Antarctic ozone anomaly with you.

In the interest of time, I am going to summarize a somewhat longer written statement that I submitted for your consideration.

The Antarctic ozone anomaly was first detected by the British Antarctic Survey. Their data, from about 1957 to 1975, recorded year-to-year variations of the monthly averages of ozone fluctuations on the order of 10 percent or so, undoubtedly caused by natural variability in atmospheric dynamics. Such fluctuations are routinely observed everywhere in the world.

Over about the past 20 years, on the other hand, the ozone observed in the Antarctic spring has decreased rather systematically, so that the ozone layer over the Antarctic today is only about half as thick as it was in the late 1960s and early 1970s.

This remarkable and unexpected change in the ozone layer has come to be known as the Antarctic ozone hole. A number of theories have been advanced to explain the ozone hole through chemical or dynamical processes. There are basically two different types of chemical theories that have been published in the scientific literature.

An interagency National Ozone Expedition, funded jointly by the National Science Foundation, the National Aeronautics and Space Administration, the National Atmospheric Administration and the Chemical Manufacturers Association went to Antarctica during August to November 1986 to examine the ozone hole first-hand and to try to measure a broad range of chemical compounds.

You have asked me to try to describe the chemical theories and the observations made by the National Ozone Expedition which bear upon those theories.

The interaction of the sun with the earth's upper atmosphere produces oxides of nitrogen at altitudes about 100 kilometers above the surface. It was suggested that enhanced levels of nitrogen oxides associated with high solar activity levels near 1980 could be responsible for the depletion of the Antarctic ozone.

The scientists from the British Antarctic Survey suggested that the cause of the ozone hole was chlorofluorocarbons and that the unique conditions of the Antarctic could make this region particularly susceptible to ozone destruction by chlorine.

Measurements indicated that chlorofluorocarbons are nearly uniformly distributed throughout the world, even though they are produced mostly in the Northern Hemisphere. This occurs because they are rapidly mixed by atmospheric dynamics.

A number of other scientists have suggested important additions or modifications to the work by the British Antarctic Survey. The temperatures in the Antarctic stratosphere are, indeed, the lowest, by far, of those occurring anywhere in the stratosphere and are sufficiently low that clouds often form in the Antarctic through winter and early spring.

We already heard a little bit about those clouds this morning. These clouds are only very rarely observed elsewhere on the planet. A number of laboratory studies, including a particular one by Professor Rowland and his colleagues, suggested unusual chemistry occurring on cloud surfaces reduce the level of nitrogen oxides and increase those of chlorine oxides, which can then go on to destroy ozone effectively in this region.

It has been pointed out that the interactive chemistry of chlorine and bromine might be particularly important in the ozone loss under these conditions. A synergistic effect between these two species can make them much more effective at destroying ozone than either in isolation.

The ozone hole is a strongly seasonal phenomenon. The National Ozone Expedition did a lot to clarify our understanding of the vertical and temporal changes in ozone associated with the hole. We arrived in Antarctic in late August to find total ozone levels and profiles that I would describe as close to normal for that latitude and time of year.

In the next several weeks, we witnessed about a 35 percent reduction of the ozone overhead. In addition to the strong evidence provided by the historical data extending back to the 1950s and 1960s showing a long-term trend in Antarctic ozone, I want to emphasize that the behavior observed in a single spring season clearly reveals the growth of the hole. Similar trends have been established from other ground-based and satellite studies.

It would be highly desirable to make future observations earlier, say, in early August, to much more fully study the seasonal cycle of the hole.

The levels of nitrogen dioxide and nitric oxide observed in the Antarctic during the National Ozone Expedition were extremely low, only about one-third as large as Arctic observations.

These low abundances are consistent with halocarbon theories of the ozone hole involving unique surface chemistry of polar stratosheric clouds but do not prove that such models are correct. They do, however, demonstrate that the chemistry of the Antarctic stratosphere is quite anomalous with respect to other observations at other latitudes or standard theory neglecting such surface reactions.

Balloon measurement made during the National Ozone Expedition displayed a maximum seasonal change in ozone near 15 to 20 kilometers altitude, while the solar activity theory predicted larger changes at higher altitudes. These observations, as well as the unusually low levels of the oxides of nitrogen observed, are in conflict with predictions by the solar activity theory.

Observations of chlorine-containing molecules are of prime importance in studying the possible role of halocarbon chemistry in the development of the Antarctic ozone hole. Chlorine monoxide, as we will hear about from Dr. Phil Solomon, was measured by the ozone expedition and was present at about the one part per billion by volume level near 20 kilometers.

This is about 100 times greater than standard model predictions and is roughly consistent with some models of the ozone hole invoking halocarbon history possibly associated with polar stratospheric clouds.

Chlorine dioxide is a closely related molecule which is believed to reflect the important chemistry of both chlorine and bromine. It was also found to be present in an amount some 20 to 50 times greater than standard theory in agreement with the chlorine monoxide measurements and with some halocarbon theories.

The two observations taken together clearly demonstrate that the chlorine chemistry in the Antarctic stratosphere is highly anomalous. There are a number of important uncertainties involved in this anomalous chemistry and its possibile relationship to the ozone hole. Foremost among these are uncertainties in the rates of critical kinetic processes. These must be better quantified by laboratory studies.

The chemical observations that I have discussed establish that the chemistry of the Antarctic stratosphere is anomalous but do not prove these anomalies are sufficient to be the sole cause of the ozone hole.

Mr. Chairman, this concludes my formal presentation. I want to thank you again for the opportunity, and I will be glad to answer any questions that my testimony elicits.

Senator BAUCUS. Thank you, Dr. Solomon.

You have been a very valuable witness here and in other hearings, as well. Thank you.

Dr. Tung?

STATEMENT OF DR. K.K. TUNG, CLARKSON, UNIVERSITY, POTSDAM, NY

Dr. TUNG. Mr. Chairman, I thank you for the opportunity to discuss before you dynamical theories that have been proposed to explain the ozone hole phenomenon.

During the past year and a half, many of us have been working very hard to come up with a theory to account for this very unusual and unpredicted phenomenon that we have been seeing in Antarctica.

There are two kinds of theories that have been proposed: One is chemistry, which mainly tries to relate depletion in the ozone over Antarctica to increased levels of CFC's.

The other type is dynamical, which tries to relate changes in ozone over Antarctica and also over other latitudes in other parts of the world to changes in air circulation patterns.

I have summarized in my written statement several theories that have been proposed. I would like to just emphasize that there has not been enough time for the scientific community to come to a consensus as to whether the phenomenon is chemically caused or is it a manifestation of dynamical fluctuations.

There is not even a consensus as to whether the decline in ozone that we have been seeing in the last 6 or 7 years constitutes a long-term trend or is simply a coincidence of three large decreases: one occurring in 1980; the other in 1983; and the last one in 1985. That is, we are not sure if the trend we are seeing, the so-called trend, is merely a coincidence of three large drops of about 15 percent a year or so.

Also complicating the matters, the ozone drop in Antarctica has not been monotonic. That is, the 1986 ozone level in Antarctica was higher than in 1985. Ozone in 1984 was higher than in 1983. It has been going up and down and up and down.

So I would say that we will be very interested in finding out what will happen to the Antarctic ozone hole in the next 2 years. But we will not be able to predict with enough confidence, based on past records, whether or not the downward trend will continue.

There appears to be a common misconception that the ozone layer is a static entity and that it is sitting there waiting for chemicals to destroy it. It is amazing to note that the concentration of ozone over the tropics, where most ozone is produced, is actually very low all year round. We see higher concentrations of ozone over the Arctic, where we do not expect it to be based on purely chemical theories. The reason for the distribution of ozone in the world being the way it is today is because of the important role played by dynamics, transporting ozone from the tropics to high latitudes. And since ozone over high latitudes is there because it is brought up there by the air circulation patterns, so any change in dynamical fluctuations of such air circulation patterns would very sensitively affect the concentration of ozone in mid to higher latitudes.

Our computer calculations, based on the latest model incorporating coupled dynamics, radiation and chemistry developed under support from NASA, tell us that ozone content over mid to high latitudes is quite sensitive to year-to-year, as well as seasonal temperature changes. Quantitatively, we have found that for every two degree centigrade drop in temperature in the lower stratosphere, there is a 5 percent drop in the total column ozone content overhead.

So the observed 40 percent drop in Antarctic column ozone from 1979 to 1985 can be accounted for by a 16 degree drop in temperature in the lower stratosphere over Antarctica. Such a temperature change has been reported by Drs. Newman and Mark Schoeberl of NASA, and it has been published in the November 1986 Geophysical Research Letter.

I should emphasize, however, that there is still controversy surrounding these measurements, and there is still some uncertainty concerning the accuracy of measurements and the accuracy of the models on which those calculations are based.

I can say that there is, again, no concensus in the scientific community concerning this point. My own opinion is that the Antarctic ozone will continue to go up in some years and down in some other years in a more or less zig-zag pattern. Whether or not, after you remove this larger dynamical fluctuations, there is a smaller underlying trend that can be attributed to chemistry, in particular, to increases in CFC emissions, is not certain at this point.

We do not feel that we are confident enough to be able to filter out this larger dynamical component and arrive at the smaller trend at this moment. This last comment also applies to ozone data from the Northern Hemisphere and even to globally averaged ozone content. It is well known that the atmospheric ocean system fluctuates in a variety of time scales ranging from a couple of years to as long as 40 years or more, and therefore, I would advise caution in the interpretation of long-term trends in ozone data.

Thank you.

Senator BAUCUS. Thank you very much, Dr. Tung.

Dr. Hofmann?

STATEMENT OF DR. DAVID J. HOFMANN, PROFESSOR OF PHYSICS, UNIVERSITY OF WYOMING

Dr. HOFMANN. Mr. Chairman, members of the subcommittee, I appreciate this opportunity to report on measurements which were conducted in Antarctica during the period August to November 1986. As part of the National Ozone Expedition to McMurdo Station, the research team from the University of Wyoming Department of Physics and Astronomy conducted a high altitude balloon study of the ozone hole region of the atmosphere.

The measurements included 38 balloon flights to altitudes in the region of 30 kilometers, or about 100,000 feet, between August 26 and November 7. The vertical distribution of ozone was measured on 33 occasions, and the aerosol particle distribution was measured on six occasions.

The purposes of the ozone measurements were to determine the altitude of the ozone depletion phenomenon and the rate at which ozone disappeared in the Antarctic spring. The purposes of the particle measurements were to study the nature of the wintertime stratospheric particle distribution and to attempt to detect polar stratospheric clouds, and also to use the particle measurements as chemically independent tracers of air motions to assess dynamic models of ozone depletion which involve up lifting of air over Antarctica in the spring.

The results. The ozone measurements indicated that ozone depletion occurred only between the altitudes of about 12 to 20 kilometers, that is, a region from about 40,000 to about 66,000 feet. The depletion began at the top of the region in late August and progressed to lower altitudes, ending in mid-October at the bottom of this region. The decay of ozone in the middle of this region, that is, at an altitude of about 18 kilometers or 60,000 feet, continued very smoothly throughout September and indicated a half-life, that is, the time for the amount of ozone to be reduced, by a factor of two, of about 25 days.

The ozone vertical profile, as measured during the balloon ascent, indicated a great deal of structure, especially after mid-October.

In these subregions of 1 to 5 kilometers, reductions as great as 90 percent in the amount of ozone were observed.

The particle measurements indicated that there were no upward motions at any time during the period of measurements. This was by two independent methods, one of large particles residing normally in the stratosphere and one of very small particles which are normal tropospheric components, which were not observed in the stratosphere.

In fact, the data are consistent with continued subsisdence in spring, as it occurs throughout the winter season. At no time were the particles observed which had the size which would be expected from various theories of polar stratospheric clouds. High concentrations of very small particles were observed above the region of ozone depletion. The significance of these small particles is unknown at this time.

Data interpretation. The observation of the limited spatial region over which the depletion of ozone occurs and the fast rate of decay place severe limits on any model, chemical or dynamical, which purports to explain this phenomenon. Although the observed structure in the ozone profile could be the result of dynamics, that is, horizontal motions of air within the polar vortex, or of chemical depletion in spatially limited regions, the uniform decay observed throughout September plus the lack of vertical motions indicated by the particle measurements favor a chemically based depletion phenomenon during this period.

Several features of the ozone depletion, for example, the limited altitude region and the time development, show great similarily to both the altitude and disappearance of polar stratospheric clouds in the springtime. This suggests if not a causal relationship, at least a process which appears to affect both these species.

The apparent absence of particles which could be identified as polar stratospheric clouds in the measurements suggests that these cloud particles may be quite large and at a concentration level which is so low as to preclude their detection in the balloon-borne equipment employed. We estimate that there was about a 90 percent probability that we should have seen these particles if they were of the size that was predicted by theory.

We now believe that these clouds consist of quite large particles at very low concentrations. This interpretation, while it does not agree with current theories of clouds, does not change their possible importance in heterogeneous chemical processes.

Plans for the future. We plan to repeat the 1986 measurements in the same timeframe as in 1987. Additional particle flights will be conducted to increase the probability of penetrating a polar stratospheric cloud. We feel that if we make enough of these soundings, we can definitely conclude if the particles are, indeed, very large. This increased frequency of particle measurements will also allow us to determine the subsidence rate of air in the polar vortex to a greater degree of accuracy, and to look more closely at the dynamical theories.

The ozone profile will be measured approximately every two days so as to again map out the spacial/temporal nature of the depletion phenomenon so that we may compare it with the 1986 data and assess any increase or diminution in the depletion phenonenon which may occur.

Thank you.

Senator **Baucus**. Thank you, Dr. Hofmann.

Dr. Solomon?

STATEMENT OF DR. PHILIP M. SOLOMON, STATE UNIVERSITY OF NEW YORK AT STONY BROOK

Dr. **Solomon**. Mr. Chairman and members of the Committee, it is a pleasure to be here and present the results of our measurements. The Stony Book Antarctic research is a joint effort involving three senior personnel.

The SBA research is a joint effort which involves three senior personnel at the State University of New York.

Our observations utilize the technique of ground-based millimeter wave spectroscopy, which has been adopted from the science of radio astronomy. The instrument has the capability of observing signals during either the day or night from trace constituents in the stratosphere and can measure the quantity and approximate altitude distribution of the specific chemicals responsible for the emission. This millimeter wave receiver can be tuned to receive signals much like a radio from a particular chemical of interest.

The principal goal of our observations during the 1986 National Ozone Expedition was to measure emission from chlorine monoxide, a chemical directly involved in a catalytic cycle which can destroy ozone. All of the chemical models for the origin of the Antarctic ozone hole require the presence of abnormally large quantities of chlorine monoxide in the lower stratosphere. Its presence is, thus, a necessary condition for the operation of halocarbon destruction and a critical test of the models which suggest that the ozone hole results from man-made chlorofluorocarbons, the main source of stratospheric chlorine.

Our measurements show that during the first 3 weeks of September, chlorine monoxide was present in two layers of the stratosphere: An upper layer, centered between 35 and 50 kilometers, and a lower layer concentrated between about 15 and 25 kilometers. The measurements of the upper layer show normal chlorine monoxide, similar to quantities we have found elsewhere.

The upper layer can be understood by standard chemistry and has nothing to do with the Antarctic ozone hole. However, the emission from the lower stratosphere was very unusual. We found about 100 times more chlorine monoxide at an altitude of 20 kilometers in the stratosphere than is present in other parts of the world. The mixing ratio of chlorine monoxide at 20 kilometers was about one part per billion by volume, which means that roughly a third or a half of the total chlorine was in the active form of chlorine monoxide. The altitude of the excess chlorine monoxide is also the altitude of maximum ozone depletion.

Furthermore, there is a day-night cycle present in the data. The amount of chlorine monoxide decreases at sunset, reaches a minimum or vanishes at night, and returns to its peak value near noon. This diurnal cycle is an expected characteristic of chlorine photochemistry. At night the chlorine monoxide combines with other chemicals into one of several reservoir species which are then photolyzed, producing chlorine monoxide when the sun rises in the morning.

Further evidence on the nature of Antarctic chlorine chemistry comes from our observations of weekly changes during the September–October period. We found a high concentration of chlorine monoxide during the first half of September, followed by a graduate decline in the second half of September and little or none by October 8 through 12. The highest concentrations of chlorine monoxide also occurred at the same time as the lowest stratospheric temperatures and the disappearance of chlorine monoxide in the beginning of October coincided with a substantial warming of the stratosphere.

These low temperatures are also required for the presence of polar stratospheric clouds, another important ingredient of existing chemical depletion models. The presence of abnormally large quantities of this chemical in early September and its disappearance in October point towards chlorine as playing an important role in the origin of the springtime Antarctic ozone hole. These observations support the class of models in which chlorine from manmade chlorofluorocarbons is at least part of the cause of the Antarctic ozone hole.

There remain, however, many uncertainties in the models, which need to be tested. During the National Ozone Expedition to Antarctica, we also obtained measurements of emission from nitrous oxide. Although not a direct part of any ozone destruction cycle, nitrous oxide can be used as a tracer of atmospheric dynamics and a test of dynamical models, since it is a ground source chemical.

Our results are totally unexpected. We found much less nitrous oxide in the stratosphere above 15 kilometers than expected or predicted by any type of model.

The very low quantities of nitrous oxide which we found also demonstrates that the ozone hole cannot be caused by a simple dynamical uplifting or transport of air from the troposphere to the stratosphere.

In summary, the nitrous oxide observations are in conflict with models of dynamical uplifting as the cause of the ozone hole. Our observations of chlorine monoxide, give support to that class of models which involve anthropogenic chlorofluorocarbons as a cause of the Antarctic ozone hole.

The excess chlorine monoxide we have found might be said to be analogous to finding a smoking gun. The evidence is pretty strong, although we have not quite seen the chemical gun being fired.

We plan to repeat our measurements in Antarctica during the 1987 expedition with some improvements in instrumentation to more accurately measure the altitude of the excess chlorine monoxide and to confirm our results on nitrous oxide.

Mr. Chairman, I want to thank you for this opportunity to present our results, and I will be glad to answer any questions.

Senator **Baucus**. Thank you very much, Dr. Solomon.

Dr. Farmer, you are next.

STATEMENT OF DR. CROFTON B. FARMER, JET PROPULSION LABORATORY, CALIFORNIA INSTITUTE OF TECHNOLOGY

Dr. **Farmer**. Mr. Chairman, members of the Subcommittee.

I am pleased to be here today to describe the results of the observations which my group from the Jet Propulsion Laboratory made in Antarctica last year.

We used the technique of high resolution infrared absorption spectroscopy, using the sun as the radiation source, to make measurements of the detailed composition of the atmosphere.

Since this method allows us to identify and record the variations of many different gases, our approach was to make diagnostic tests of the several hypotheses that are being proposed to account for the seasonal ozone depletion by examining the behavior of the relevant chemical species.

First, I should say that our data were of excellent quality, despite our apprehension in taking a new and complex system to this rather difficult environment. Consequently, we feel that high confidence in the quantitative accuracy of the results of our analysis of the spectra is justified.

In the written statement which I have prepared for the record, I have described our findings relative to the behavior of ten different molecular species, each of which bears on some aspect of the problem. Before summarizing the implications of these results, I should point out that because of the length of time required to complete the analysis of this large amount of data, our results have not yet been submitted for publication in the scientific literature.

As you are aware, there are three types of mechanisms proposed to explain this phenomenon: dynamical, solar and chemical. In the first of these, a reversal of the vertical motion of the atmosphere is invoked, which carries ozone-poor tropospheric air up into the stratosphere. If this were indeed occurring, one would expect to see the uniformly mixed gases lifted also, with an increase in their over-burdens.

We observed no change in the columns of methane and nitrous oxide. They were highly constant, whether we were inside or outside the hole. In fact, their column amounts were somewhat reduced, indicating that the motion was downward rather than upward.

In the second class of hypotheses, enhanced levels of the nitrogen oxides are suggested, produced by increased solar activity. Here again, our results indicated the opposite. The oxides of nitrogen were considerably reduced and never reached their normal, mid-latitude levels.

In the third class of explanations that we might refer to as the "chlorine mechanisms," several different detailed schemes which you have heard about today are suggested. There are some common features, however, among these that one would expect to observe in testing the validity of the ideas.

These include the presence of frozen forms of the reservoir gases; low levels of the nitrogen oxides; and significant differences in the relative amounts of the chlorine-containing gases resulting from the unusual chemical paths invoked in the postulated reactions.

We observed all of these necessary conditions. But particularly important, in my view, were the distribution of the chlorine between its reservoir forms, hydrochloric acid and chlorine nitrate (as shown in the figures appended to my written statement) which was very different from the situation in the normal, or mid-latitude, atmosphere.

Second, the high levels to which the total chlorine abundance grew as the solid particles evaporated; and third, the observation of the partitioning of the chlorine returning to normal at the end of October.

In addition, we were successful in making a measurement of the amount of hydrogen fluoride, a stable end product for the fluorine released from the CFC's, which provides a reliable indicator of the halegen budget in the atmosphere and which verified the high chlorine values.

My conclusions from our results thus far are:

First, that there is no doubt that the chlorine chemistry of the Antarctic stratosphere is perturbed during the early spring season.

Second, the role of processes occurring on or in frozen particles in the lower stratosphere appears to be substantiated.

And third, while these results do not prove that there is a cause-and-effect relationship between halogenated source gases and the the seasonal ozone depletion, they are entirely consistent with such an explanation.

Thank you, Mr. Chairman.

Senator Baucus. Thank you, Dr. Farmer.

Dr. Tuck?

STATEMENT OF DR. ADRIAN TUCK, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Dr. Tuck. Mr. Chairman and members of the Committee, my name is Adrian Tuck. I work as the Program Chief in Meteorological Chemistry at the NOAA Aeronomy Lab in Boulder. I am the project scientist for the mission that is due to take place this August and September that will be based in Punta Arenas on the Magellan Strait at the tip of South America.

It has been funded jointly mostly by NASA, but also with substantial contributions from NOAA, NSF and CMA. The Antarctic ozone hole is exciting from a scientific point of view because it is the first time that a chemical problem connected with the ozone budget has come within reach of the range of an aircraft. With an aircraft, of course, you can recover much more than in a satellite and you can launch it much more easily than a balloon.

The mission was possible because of the existence of the ER-2 high-altitude research aircraft that NASA has had equipped with a number of instruments for investigating stratospheric and tropospheric exchanges around the high thunderstorms in the tropics, and which indeed was successfully used for that this January and February in Darwin, Australia. With some additions, it turned out to be a very powerful tool for looking at the ozone hole problem.

The enhancements which were necessary were the addition of an instrument to measure chlorine monoxide, which is the molecule that will carry the three different chain reactions that have been proposed as being possible in the chemical versions of the ozone hole depletion, and also bromine monoxide.

It will also measure ozone, total nitrogen oxide content, water vapor and has measuring capability for looking at particulate matter, PSC, and aerosol particles. It also has a capability for measuring molecules which are tracers of atmospheric motions. So the payload does actually carry instruments which address all the range of components of the theories.

The important point about the ER-2 is that it can actually fly in the very region of ozone depletion. We are not dependent on looking at it remotely; we are actually in it. The measurements are made with a very fast response time. However, when the mission was being planned and formulated at the early stages in the middle of last year, we realized that there was a DC-8 four-engine aircraft that was also available, possibly; everybody thought that the engineering schedule was ridiculous, that it couldn't be done in time.

It has turned out that with the characteristics that this mission has found everywhere, namely that we have had nothing but splendid cooperation and a "can-do" attitude from everybody involved. Although the schedule is still very success-oriented, it has turned out that the DC-8 can be and is being equipped with four remote sounding instruments. The DC-8 can't fly any higher than the very bottom extremes of where the ozone hole is, but with these remote sounding instruments, it can look upward rapidly and remotely at the chemical content of the air above it.

Unlike the ER-2, it has a much longer range. It can penetrate much farther into the vortex. We plan to have it fly across the South Pole from South America to New Zealand. The upward-looking instruments will map out a slice right across the entire vortex of what is going on.

I think with the two aircraft together, this is a very powerful mission. If one looks at the scientific interpretation of aircraft flights, it is always very difficult. If what you do is say, "I am going to fly with respect to fixed geographical coordinates," it is very hard to work out how those aircraft measurements can be sensibly compared with existing models, and the normal sort of feedback time that one has for an aircraft mission is months and even years.

You do the scientific interpretation, and then two or three years downstream you say, "If I was going to do that again, I would do it differently." Now we have tried to do something about that. We are trying to do some real time chemical models as the results come in from the airplanes. We are trying to put together a chemical package in a Lagrangian coordinate system, and to do the best forecasting of air motions that we can for very pressing reasons of aircraft safety, because the ER-2 is very susceptible to cold temperatures and to side winds.

We have had to put a lot of money into telecommunications to get meteorological information, and obviously, if you are going to try and fly airplanes into the ozone hole, you need to know where it is.

It is a nice, comforting picture to think that it is there all the time in September and October, but when you actually look at the detailed morphology from day-to-day, it varies quite a lot. You don't want pilots to take unnecessary risks if you are not reasonably certain they are going to find something unusual.

So the major problem that we feel we may have is with actually getting into the ozone hole. We are having real-time satellite data from TOMS, the total ozone mapping spectrometer on Nimbus 7. We will have that in near real time.

We are doing our best to have forecast meteorology to tell us where the ozone hole is. If you refer to pages 6 and 7 of my testimony, I have laid out there the science questions and what I think we can do in the way of answers for our payload.

In concluding, I think we have got a very success-oriented schedule. There are potentially problems with the weather, but nevertheless, I feel reasonably confident at this stage that we have got a payload that can provide us with some very exciting scientific answers in the timescale of September and October.

Thank you.

Senator BAUCUS. Thank you very much, Dr. Tuck.

Dr. Solomon, why is it there is a dynamic phenomenon? My gosh, in the next sentence, someone would say, in fact, Dr. Tung has, that it is Antarctic. After all, it is colder; there are different geologic and different meteorological phenomenon down south compared to other parts of the globe. Cyclically, there are ups and downs. It is coincidental. There happened to be some big drops in the stratospheric ozone depletion at one time. Why isn't this dynamic? What is wrong with that argument?

Dr. SOLOMON. Let me just say that I don't think anywhere in my testimony did I say that I absolutely did not believe that it could be a dynamical mechanism. I think there is some possibility that indeed, the Antarctic ozone hole is caused by dynamical processes. I think it is unlikely but not impossible. The reasons I think it is unlikely are fairly simple.

As Dr. Tung has pointed out, some measurements—well, let me backtrack just a bit. In order for the Antarctic ozone trend to be explained by a dynamical mechanism, there would have to be quite a considerable change in temperature over about the past ten to 15 years, the time scale over which the ozone trend has happened. One would require something like a 20-degree change in temperature in the Antarctic stratosphere to explain such a trend in the ozone by the dynamical mechanism that Dr. Tung advocates and has advanced.

So the question is: How large a temperature change exists in the Antarctic? There are some measurements that indicates that it may, indeed, be as large as 20 degrees. There are others that indicate that it is much smaller, perhaps only three degrees.

That kind of change, only three degrees or so, it would be an effect of the ozone change rather than a cause. Because as ozone changes, as ozone decreases, temperatures should go down slightly by about five degrees or so.

So an observation of a three degree change in temperature would be consistent with the idea that the fundamental cause, if you will, of the ozone hole is a chemical one, not a dynamical one. The observation of a 20-degree temperature change is quite another matter. That could, indeed, indicate that the change is due to the weather.

The critical question is: How large a temperature change has occurred in the Antarctic? Is it sufficient to explain the ozone change that has occurred there? There are a variety of views on that subject.

Senator **Baucus**. Does anyone else want to address the problems of the dynamical theory? Dr. Hofmann?

Dr. **Hofmann**. The theory as proposed is based on depletion of total ozone. That is the total amount of ozone throughout the atmosphere. These theories, then, suggest that you only need an uplifting of something on the order of one kilometer a month to account for the reduction of total ozone during September.

The balloon measurements show that the depletion does not occur throughout the stratosphere; it occurs in a very limited slice, and if you look in this region, such a dynamical theory would require an uplifting of five kilometers per month.

I think this is completely out of the realm of possibility of such a theory.

Senator **Baucus**. Dr. Solomon?

Dr. P. **Solomon**. Also, as I mentioned in my testimony, our observations of nitrous oxide show pretty conclusively that if anything, the atmosphere is pushed down rather than up in Antarctica.

If there were a true uplifting we would have seen more nitrous oxide especially with our technique, which is more sensitive to the nitrous oxide above 20 kilometers than in the lowest levels of the stratosphere. I think there is some experimental evidence against a simple dynamical argument.

Senator **Baucus**. Dr. Farmer?

Dr. **Farmer**. I would add that our measurements of N_2O, methane, and nitrous oxide all support Dr. Hofmann's statement that the motion is downward rather than upward.

Senator **Baucus**. Dr. Tung, now is your chance.

Dr. **Tung**. Yes, I am the only one here.

Senator **Baucus**. Why are all these other people incorrect? What is your best argument for the dynamic theory? What is your best argument as to why the chemical theory just doesn't hold water?

Dr. **Tung**. I have never said the chemical theories would not hold water. I agree that there is evidence that the chemistry in the Antarctic is anomalous; there may be evidence of more heterogeneous chemistry, but that is a separate matter from the ozone chemistry. That is, we are not sure how much of this anomalous chemistry is actually causing the ozone destruction of the magnitude that has been observed.

It could account for 50 percent; it could account for 10 percent; it could account for 2 percent. We are just not sure which number it is. I think most people here will agree with me on that statement.

Concerning the evidence of whether or not there is upward motion, the problem of us doing science in a fish bowl is that I heard the evidence presented here today for the first time and so it does not give me a chance to look at it and analyze it and respond to it. I think that is the nature of our problem here.

But on prior occasions, when some unfavorable so-called evidence was presented, we always found out later that there had been a misunderstanding of the way dynamics work. For example, the upward circulation that we have proposed and we have produced from our computer models only occurs between 15 kilometers to 25 kilometers. It is a very limited, small recirculation region.

If the chemical distribution is such that the bulk of N_2O and methane is occurring below 12 kilometers, then it would not be able to see the effects of the recirculation motion above 15 km. Concerning Dr. Hofmann's measurements, we have debates and arguments among ourselves. I was surprised today he spoke with such certainty about his interpretations.

We do not understand the sources and sinks of aerosols. If the aerosols and ozone are the same, and that they have the same vertical and the same horizontal gradients, then you would expect that whatever happens to the ozone should happen to the aerosols.

It just happens that the volcanic aerosols do not have the same gradients and we also do not know its formation and destruction process well enough for us to make such certain statements at this point.

Senator **Baucus**. Thank you. I see my time is up.

Senator Durenberger is here. He is cochairing this hearing; he is also ranking. Do you have a statement? I am sorry.

Senator **Durenberger**. I do have a statement, but I would ask unanimous consent that it be included in record.

Senator **Baucus**. Without objection.

[Senator Durenberger's statement follows:]

Opening Statement of Hon. Dave Durenberger, U.S. Senator From the State of Minnesota

Mr. Chairman, I would begin by recalling the last hearing we had on this subject which was earlier this year. At that hearing we had essentially three views represented. We had a panel of scientists who discussed the evidence for global ozone depletion. We had a panel of government officials who were on their way to Vienna to negotiate an ozone protection protocol. And we had four or five Senators up here who had just introduced legislation to reduce chloroflourocarbon production in the United States.

At the time I observed that the scientists thought more research was necessary, the negotiators thought more negotiation necessary, and those of us on the subcommittee argued that the only prudent course was more legislation.

Some new elements will be added to our discussion over the next three days. Two new groups will be joining us in this room—the producers and the users of CFCs. If they behave like the rest of us, they may well argue that more production and more use of chloroflourocarbons and halons are essential to their businesses and to our economy.

But there have been developments since the last hearing which may also bring us closer to a consensus on what must be done. The scientists will report new evidence which supports a chemical theory as an explanation for the events in the Antarctic. And they will describe studies for the coming expedition which will greatly improve our knowledge of the atmospheric events which lead to ozone depletion.

In the same vein, the negotiators are back from Europe and will, no doubt, give us a very positive report on the international discussions and the possibility that a large number of developed countries are ready to freeze and reduce the production of CFCs.

If we could also secure one other piece of good news from the producer and user groups—that being the promise of effective and economical substitutes in the near-term—these hearings might actually conclude on a very hopeful note. That's the one piece that could bring this all together that is missing at this point.

Bringing each of the various pieces into harmony with a legislative program is still our task. I look forward to working with the Chairman and other members of the Subcommittee as our efforts—and the efforts of each of the other four groups who join us in this discussion—evolve over the next few months.

Thank you, Mr. Chairman.

Senator **Baucus**. Senator Chafee?

Senator **Chafee**. Thank you, Mr. Chairman.

Dr. Tung, Dr. Philip Solomon didn't equivocate at all when he, on page 2 of his statement, says,

> The emission from the lower stratosphere is very unusual. We found about 100 times more chlorine monoxide at an altitude of 20 kilometers than is present in other parts of the world.

That is quite a difference, isn't it?

Dr. **Tung**. Yes, and that is the basis on which I base my statement that I agree that the chlorine chemistry in Antarctica's lower stratosphere is anomalous; that there is nonstandard chemistry going on there.

But it is a separate question, as I emphasized, concerning whether that non-standard chemistry is causing the ozone depletion of the magnitude that we observe.

Senator **Chafee**. Let me ask everyone a question. We are hearing a lot about the Antarctic, and that is fine, but suppose you go back to take another look and you found that chlorine alone cannot cause a massive depletion of 40 or 50 percent each year over the Antarctic or that something specific about the Antarctic will limit such massive depletions of the dynamic theory, no matter what it is. Nonetheless, would such a finding undercut the theory of models showing lesser but still significant depletions around the globe?

That is my question. Is everything hinging on these Antarctic results?

Senator **Chafee**. The Dr. Solomons, Philip Solomon?

Dr. P. **Solomon**. In my personal view, the Antarctic phenomenon is very special, and I think it would be dangerous to extrapolate to the world from Antarctica.

I must say that when I went down to Antarctica, by the way, I thought the phenomenon would probably end up to be dynamical, but——

Senator **CHAFEE**. You went with an open mind?

Dr. P. **SOLOMON**. I went with an open mind, yes. Part of the reason I had an open mind was that, as I must say, I found that the models in all of the theories were quite at variance one with another. I come from outside the field. I am really an astronomer, and I was quite surprised to find that the theories which try to explain the Antarctic phenomenon were just as speculative as the theories which try to explain cosmology or phenomenon in our galaxy.

So I went with an open mind, but as I said, my personal view now is that it would be dangerous to extrapolate from Antarctic.

Senator **CHAFEE**. What would you say to that, Dr. Hofmann? My question really is that the problems with global ozone depletion and the Antarctic hole are still separate issues.

Dr. **HOFMANN**. I think in general, that is true. However, I think we should be concerned about ozone measurements mainly taken from satellites which suggests there are sizable depletions at latitudes of 45 and 50 degrees south that are of the order of 10 percent or so. These latitudes are completely out of the region of these very cold temperatures where one would expect the formation of clouds.

If this data is correct, then we have to be concerned with how ozone is depleted in this region. Then we are talking about possibly other regions of the globe that could be similar.

Senator **CHAFEE**. I do want to say, Dr. Hofmann, I know Senator Simpson is a member of this Committee, and unfortunately, he had a leadership meeting down at the White House this morning. But I know that if he were here, he would want to extend a special greeting to you coming from his home State.

Dr. Solomon, what have you got to say about that?

Dr. **SOLOMON**. Let me just comment. My colleague, Dr. Philip Solomon, says he went to Antarctica with a completely open mind: He already knew it was dynamics.

Dr. P. **SOLOMON**. I suspected it to be.

Dr. **SOLOMON**. Let me just talk a little bit, then, about this question of whether the Antarctic ozone phenomenon can spread to other latitudes, because I think that is what you are really driving at, or what the implications are for the other latitudes.

As we have already heard, there is compelling evidence that there has been a change in the ozone at mid-latitudes at the 40 kilometer level.

However, that altitude region makes a very small contribution to the total ozone column. Most of the total column is located much lower down in the atmosphere, from about 10 to 30 kilometers. So a significant change of 40 will have only a very small effect on the total column.

At the lower altitudes, the chemistry is much more complex, and it is dependent on such things as concurrent changes in N_2O and methane, which can actually lead to ozone increases at those levels, as Dr. Watson pointed out earlier. The Antarctic ozone phenomenon demonstrates that there can be important changes at this altitude range.

The Antarctic ozone hole does happen at those very low altitudes from about 15 to 20 kilometers. We think that it probably happens because there are stratospheric clouds in there. Those clouds provide a tremendous amount of surface area. There are surfaces in other places, too. There are surfaces in the air between you and me right now. We can't see them.

We could if there was a cloud in between, but nevertheless, there is surface area available in the air in the stratosphere above Washington, DC. There is a lot less surface, and it is a very different kind of surface. Yes. It is probably 50 degrees warmer than what is in the Antarctic. Its composition is probably, it is probably liquid, sulphuric acid, whereas the Antarctic particles are ice, more than likely, and they also probably contain nitric acid and hydrochloric acid. We simply don't know whether or not the same kind of physical process that can happen on an ice surface at minus 80 degrees celsius can happen on a liquid sulfuric acid surface at minus 30 or 40 degrees celsus.

Until we answer that question, we can't make any extrapolation for the rest of the world based on the Antarctic phenomenon. That is my personal point of view.

Senator CHAFEE. My time is up. Could I ask one last question, Mr. Chairman?

It seems to me that the Antarctic findings so far suggest the theory of a global depletion. That seems to be that way. Never mind; let's assume they are not.

Even if that doesn't pan out that way, isn't the theory of global depletion of ozone still valid?

Dr. SOLOMON. Absolutely. We have already seen changes at 40 kilometers that are probably due to fluorocarbons at mid-latitudes.

Senator CHAFEE. Dr. Tung, yes or no.

Dr. TUNG. Yes. It is just that we should not use Antarctic ozone as evidence that such depletion has already occurred.

Senator CHAFEE. Do you agree with that, Dr. Hofmann?

Dr. HOFMANN. Yes.

Senator CHAFEE. Dr. Solomon?

Dr. P. SOLOMON. Yes, I agree.

Senator CHAFEE. Dr. Farmer?

Dr. FARMER. There is one point about this that I think is not coming out. We have, as you have heard, difficulty with describing the detailed mechanism that is occurring in Antarctic. We know the ozone is being destroyed, but we can't see precisely how, although a lot of the evidence now is stacking up to support the chemical mechanisms.

I think that Dr. Susan Solomon, who proposed one of the early mechanisms, perhaps should comment on this, but it seems to me that one of the reasons that the chlorine is able to so efficiently reduce the ozone in Antarctica is that the nitrogen oxides are reduced, and a lot is being said for both the bulk atmosphere as well as Antarctica about the effect of excess chlorine.

When the nitrogen is tied up by some of the chlorine and there is excess chlorine available, it can do what it does so much better than nitrogen, in destroying ozone. The fear has always been we would eventually have an excess of chlorine at the lower latitudes. This is a non-linear process.

Senator CHAFEE. You have to speak into the record. I am over my time here, so I don't want to abuse it.

Dr. FARMER. I would just finish by saying that the evidence in Antarctica is a pointer.

Senator BAUCUS. Go ahead, Senator, if you want to continue.

Senator CHAFEE. Dr. Tuck, do you agree that even if what seems to be the conclusions on the Antarctic aren't so, nonetheless, the theory of the global depletion of ozone is still valid? Do you agree? Yes or no?

Dr. TUCK. You are going to get a "don't know" to that question.

Senator CHAFEE. Okay. Thank you.

Thank you, Mr. Chairman.

Senator BAUCUS. Senator Symms has entered.

Senator SYMMS. No questions, Mr. Chairman.

Senator BAUCUS. Senator Stafford?

Senator STAFFORD. Thank you, Mr. Chairman.

Ladies and gentlemen, I am going through the same questions with you as I did with the first two witnesses. In view of the time limitations, the shorter your answers can be, the better.

I will start with you, Dr. Susan Solomon. In your judgment, does the analysis of actual measurements indicate that some portions of the stratospheric ozone layer has been depleted? And by depleted, I mean that the concentration of ozone is lower than it would be in the absence of human activity?

Dr. SOLOMON. Yes, as I have already indicated.

Senator STAFFORD. Right.

Dr. Tung?

Dr. TUNG. It is a "I don't know" to that answer.

Senator STAFFORD. I didn't hear your answer.

Dr. TUNG. I do not know.

Senator STAFFORD. I see. You are about as lonely today with this panel as we Republican moderates sometimes feel here.

Dr. Hofmann?

Dr. HOFMANN. I would agree with that, yes.

Senator STAFFORD. With which one?

Dr. HOFMANN. There is evidence for depletion.

Senator STAFFORD. Dr. Solomon?

Dr. P. SOLOMON. In Antarctica, I believe there is no question about it. Around the world, I haven't yet seen the evidence.

Senator STAFFORD. Dr. Farmer?

Dr. FARMER. Yes, in Antarctica. I don't know about the rest of the globe.

Senator STAFFORD. Dr. Tuck?

Dr. TUCK. There are places where ozone amounts are lower than they were before. Certainly, in Antarctica and possibly in the upper stratosphere. There is a big leap, though, to go from that statement to your definition of depletion. We don't know enough about the long-term historical record. The atmosphere is variable on all time scales, and we really don't know what the ozone behavior was before we started measuring it.

Senator STAFFORD. The second question, starting, again, with the left side with Dr. Susan Solomon, is it your personal judgment that there has been depletion of some portions of the stratospheric ozone layer and that in your opinion, that is all I am asking, is there any consensus within the scientific community to that effect?

Dr. SOLOMON. Well, as Dr. Tuck just pointed out, there is a lot of question about whether or not the ozone record is long enough to unequivocally establish that the changes that we are seeing now are not due to natural variability. All the evidence, though, suggests that the changes at 40 kilometers observed at mid-latitudes and the changes in Antarctica are outside of natural variability.

So yes.

Senator STAFFORD. Thank you.

Dr. Tung?

Dr. TUNG. No, I don't think there is a concensus in the scientific community. If you assemble another panel here with more dynamicists, you will get a different vote.

Senator STAFFORD. Dr. Hofmann?

Dr. HOFMANN. We agree with that, but it is mostly because a lot of the results which have been presented here have not been published. I think if you come back——

Senator BAUCUS. Results of what?

Dr. HOFMANN. The results that have been presented here have not yet been published, a lot of them. If you come back in a month or two when this information has been digested by the scientific community——

There will be general consensus, I think.

Senator STAFFORD. Dr. Solomon?

Dr. P. SOLOMON. On this point, I tend to agree with Dr. Tung. There is recent evidence on the worldwide depletion, which I just saw about a week ago, so I can't really comment on it. Short of that, I certainly have not seen any evidence which convinces me that there is a worldwide depletion given the wide range of natural variables discussed by the other witnesses.

Senator STAFFORD. Dr. Farmer?

Dr. FARMER. For the reasons that Dr. Hofmann gave, I don't think there is yet a consensus.

Senator STAFFORD. Very good.

Senator BAUCUS. Do you agree with his conclusion that once the material is published, there will tend to be agreement?

Dr. FARMER. Yes, I do.

Dr. TUCK. I don't think there is a consensus, but it appears that the tide is running in the direction of there being one.

Senator STAFFORD. Thank you all.

Question three: If there is some depletion of the ozone layer, given the analysis of actual measurements, is it your individual and personal judgment that emissions of CFCs and Halons are more likely than not to be the cause?

Dr. Solomon?

Dr. SOLOMON. More likely than not is an easy question to answer, because if I think it is 51 percent likely, I can say yes, and I think it is at least 51 percent.

Senator STAFFORD. What was that standard you gave us, 51 percent?

Dr. SOLOMON. You said "more likely than not", so yes.

Senator STAFFORD. Thank you.

Dr. Tung?

Dr. TUNG. In my opinion, when you do see a change in ozone, either going up or down, it is not all certain that it can be attributed to chemical causes. Dynamical fluctuations play a very large role in year-to-year variations in ozone at different latitudes and globally.

Senator STAFFORD. Dr. Hofmann?

Dr. HOFMANN. On the basis of the fact that I have not been able to justify any of the measurements in terms of dynamic variability, I have to go along with the chemical causes.

Senator STAFFORD. Dr. Solomon?

Dr. P. SOLOMAN. If depletion really means a long-term, downward trend, then I would say yes. If there is a true world wide depletion, it is likely to be due to CFCs.

Senator STAFFORD. Dr. Farmer?

Dr. FARMER. Yes.

Senator STAFFORD. Dr. Tuck?

Dr. TUCK. I will give a qualified yes. I still don't think that we know enough about the long-term effect of dynamics.

Senator STAFFORD. Thank you all.

Dr. Solomon, do you agree that the so-called ozone hole originally over Antarctica but now having spread to the southerly regions of South America was not predicted by the scientific community?

Dr. SOLOMON. I disagree with the second part of your question. I don't agree that the Antarctic ozone hole has been established to have spread already to South America. I think there is quite a bit of debate as to whether the mid-latitude changes in the Southern Hemisphere are a measure of something outside of natural variability. I agree the Antarctica phenomenon was certainly not predicted by anyone.

Senator STAFFORD. Dr. Tung?

Dr. TUNG. I agree with Susan Solomon here in saying that the statement about the ozone hole spreading to other latitudes is not what we think is happening. At mid-latitudes, there are decreases in ozone, but that can be accounted for by a change in temperature in that region.

Senator STAFFORD. Dr. Hofmann?

Dr. HOFMANN. Until the cause of the Antarctic ozone hole is established, for instance, whether it is connected to polar stratospheric clouds, it is very difficult to judge whether there has been any change at any other location. Certainly, that reduction in Antarctica was not predicted.

Senator STAFFORD. Dr. Solomon?

Dr. P. SOLOMON. Whatever the cause, it certainly wasn't predicted, and I believe that there was a lack of detailed understanding.

Senator STAFFORD. Dr. Farmer?

Dr. FARMER. We definitely didn't predict it.

Senator STAFFORD. Dr. Tuck?

Dr. TUCK. It certainly wasn't predicted.

Senator STAFFORD. Thank you. Thank you all very much.

I see my time is up.

Senator BAUCUS. Senator Durenberger?

Senator DURENBERGER. Thank you, Mr. Chairman. Maybe we can ask a question where we won't have to have everybody respond. I will try, at any rate, with this. As I understand, this ozone hole in the Antarctic is a month or two every spring. At the end of spring, the ozone level returns to normal.

My first question is, where does the ozone that replenishes that area of the globe come from? Is it manufactured in a chemical reaction over the Antarctic, or does it move in from other areas?

Dr. **Tung**. I think there is a consensus on the recovery portion of this phenomenon. The reason it recovers in November is because at that time we are well into spring and the polar vortex breaks down, and the ozone-rich air that was lying outside the polar vortex now gets pushed into the Antarctic region and fills the hole, so to speak.

So it is a matter of transport that accounts for the recovery, not a matter of decreased production of CFCs.

Senator **Durenberger**. Does the extreme depletion and replenishment process which occurs over a fairly large area of the Southern Hemisphere every year have any impact on the ozone level of the rest of the globe? In other words, does the ozone hole contribute to ozone depletion?

Dr. **Tung**. On a seasonal cycle, in many years, the depletion of the ozone at high latitudes, namely, over Antarctica, is compensated to some extent by an increase in the ozone levels over mid-latitudes.

In later years, the decrease in ozone over Antarctica is not accompanied by increases over the mid-latitude regions, but, instead, is accompanied by increases over the tropical area. The small increases are occurring over a much larger area.

Senator **Durenberger**. I take it from the videotapes that we have seen at various of these hearings that the ozone hole is growing rapidly. I would like to know how the chemical theory explains the rapidity of the growth and the size of the hole.

I wouldn't think the amount of chlorine available per reaction was growing nearly as rapidly as the hole seems to be.

Dr. **Solomon**. As Dr. Tung pointed out, there are year-to-year fluctuations in the depth of the hole which are due to temperature changes. One can't just look at the trend and say from one year to another year when you get a big change, that that is representative of the long-term trend.

If you look at the historical data, you will also see lots of ups and downs in the fifties and sixties. So you have to, at least as a first approximation, smooth the data over a time period of several years in order to determine the long-term trend. Even after you have done that, there is still quite a bit of question among the scientific community as to whether or not the increase in Halocarbons can quantitatively account for the rate of change of the ozone in the Antarctic.

So your point is well taken. It is not entirely clear to anybody who has done any modeling on this subject whether or not Halons can account quantitatively for the rate of decrease.

However, I could also cite a number of different reasons, arguments that I could give, that would be consistent with such a trend.

Senator **Durenberger**. The chemical theory says that chlorine and bromine are the sources of depletion and the CFC and Halons are identified as compounds which bring chlorine and bromine into the stratosphere. But there are many other sources of chlorine emissions to the atmosphere, as well.

What happens to the chlorine in all of the compounds other than CFCs which are emitted by today's society? Where does all of that chlorine end up?

Dr. **Solomon**. One known source of chlorine is methyl chloride produced by the oceans. That is the only other natural source of chlorine. All the other chlorines that are put in the atmosphere is put in by human beings.

Senator **Durenberger**. Where does it end up?

Dr. **Solomon**. Most of it, at least a large portion, ends up in the stratosphere. A Halon that contains a hydrogen atom, pointed out by the first panel this morning, reacts with a molecule in the troposphere, breaks it down, and it ends up, coming out, presumably, as hydrochloric acid.

If what you are driving at is if this makes a contribution to acid rain, I can certainly assert that it doesn't; it is not significant in terms of acid rain.

Senator **Durenberger**. Your earlier testimony, Dr. Solomon, indicated that the concentration of chlorine monoxide during the spring season over the Antarctic is about 100 times greater than theory would predict.

I take it that the total amount of chlorine in this region at that particular time was similar to the total chlorine at other places; it has just transformed into chlorine and other compounds which have a greater potential to destroy ozone; is that correct?

Dr. **Solomon**. That is correct.

Senator **Durenberger**. And the reason that this occurs is maybe because of the extreme cold and the stratospheric ice crystals?

Dr. **Solomon**. That is what we believe.

Senator **Durenberger**. Are there any events at other places in the globe, natural or manmade events, which might cause chemical and physical conditions in the stratosphere with a similar capacity to facilitate ozone destruction?

Dr. **Solomon**. Those types of clouds are dependent on temperatures dropping below about 95 degrees celsius. That happens throughout the winter and early spring in the Antarctic. It happens only very rarely in the Arctic. Such clouds are very occasionally observed in the Arctic. The frequency of their occurrence in the Arctic, I believe, is only about ten percent as great as the frequency of their occurrence in the Antarctic, because the Arctic is much warmer.

Senator **Durenberger**. I am sorry, Mr. Chairman?

Senator **Baucus**. Go ahead.

Senator **Durenberger**. I have one question for the panel at large. The skin cancer rates are not likely to go up as a result of a hole in the ozone layer in the Antarctic in wintertime, but I am wondering if there is any reason for us to suspect some possible environmental damage as a result of the existing ozone hole. Are there likely to be environmental effects from this phenomenon that are negative? If so, how large might those effects be?

Dr. P. **Solomon**. I can't say that I really know the answer to that, but it should be noted that at the time of the ozone hole, mainly September and early October, the sun is very low in the sky in Antarctica, and therefore, the sunlight passes through a large amount of ozone, even though the ozone layer is depleted. So while there is a very slight increase in the ultraviolet rays reaching the ground, the ultraviolet rays reaching the ground in Antarctica at that time is still much less than is reaching Washington today.

Senator DURENBERGER. Does anyone else have a view on possible negative effects?

[No response.]

Senator BAUCUS. Okay. Thank you.

Senator CHAFEE. Could I just ask two quick questions of Dr. Susan Solomon?

Did the high concentration of chlorine that you found in the atmosphere come from CFCs?

Dr. SOLOMON. Undoubtedly, yes. As I said, there is only one natural source of chlorine; it is methylchloride. If that were the only source, if that were the only chlorine going into the atmosphere, we would only have about one-quarter as much chlorine as what is currently observed.

Over 75 percent of the chlorine in today's atmosphere is manmade, and it is from CFCs.

Senator CHAFEE. Is there any dispute with that, panel?

Dr. HOFMANN. I would just like to mention one measurement following the eruption of El Chichon which indicated the amount of HCL doubled shortly after the eruption in the layer, but it is not clear if this was coming from the eruption itself or if it is due to a change in the chemistry within the layer which converted other compounds into HCL.

Senator CHAFEE. That is a question. Dr. Susan Solomon, three parts: When are you scheduled to arrive in the Antarctic? Is that earlier or later than last year? And does it make sense to go as early as possible? How early?

Dr. SOLOMON. That is an excellent question. At the present time, we do not have a firm schedule as to when we will be going to the Antarctica for the ground-based portion of the campaign. The Antarctic logistics are provided by the Navy.

They do a superb job at a very difficult task. They have never lost a plane in the area. Last year, we arrived in Antarctica on August 23d, and, as Dr. Hofmann pointed out, at that time, we saw that the ozone hole phenomenon had already begun.

It is critical to try to get there earlier so that we can see at what point it begins. Logistically, is it associated, for example, with the return of sunlight to this region? We also mentioned that we measured chlorine dioxide. The levels of chlorine dioxide that were observed in late August were twice as large as they were later on in September.

Dr. Solomon's measurements of chlorine monoxide showed the same thing. The question is, when does the chlorine begun to increase? How closely is it timed to return of sunlight to that region. We need to go earlier. We have asked to go earlier this year. We would like to arrive in Antarctica on August 10th. The earlier mission, obviously, has certain dangers associated with it, but it also has certain precedence.

Ten years ago, the Navy flew into the Antarctic during the winter on a monthly basis, and so apparently, logistically, they can do it.

I think it is a bureaucratic problem?

Senator CHAFEE. Let's not make judgments.

You would like to get there August 10th. Last year you got there August 23d?

Dr. SOLOMON. Right.

Senator CHAFEE. You would like to get there August 10th?

Dr. SOLOMON. Right. We can see that on August 23d, things have already started.

Senator CHAFEE. Thank you. I got the point.

Senator BAUCUS. Thank you very much. I appreciate your testimony.

Senator CHAFEE. Thank you all very much.

Senator BAUCUS. Our next panel includes Dr. Margaret Kripke, Anderson Hospital and Tumor Institute, Houston, Texas; Dr. Thomas Fitzpatrick from the Department of Dermatology at Mass General; Dr. Sidney Lerman, Emory University Shcool of Medicine, Dr. Robert Worrest, Department of General Science, Oregon State University in Corvallis; and Dr. Alan H. Teramura, Department of Botany at University of Maryland.

Dr. Kripke, why don't you begin?

STATEMENT OF DR. MARGARET KRIPKE, ANDERSON HOSPITAL AND TUMOR INSTITUTE, HOUSTON, TX

Dr. KRIPKE. Good morning.

Thank you for the opportunity to be here. I am Margaret Kripke. I am an immunologist, a research scientist at the University of Texas Cancer Center which is the M.D. Anderson Hospital.

As we have heard this morning, the effect of decreasing stratospheric ozone is, of course, to increase the amount of UVB radiation that reaches the earth's surface. What we want to discuss, I think, in this panel is the effects or the potential effects of increasing ultraviolet wavelengths in this region.

An increase of UVB radiation is expected to have a number of effects on both biological and atmospheric systems, and one of the potential consequences of UVB exposure for human health is an adverse effect on the body's immune system. That is what I would like to address my comments to this morning.

The immune system is, of course, what protects us against infectious diseases, and it also can protect us against certain types of cancer. For this reason, anything that could possibly damage the immune system or interfere with its function has at least the potential to affect human health in, I think, a very significant way.

Unfortunately, the amount of information that we have available on the effects of UVB radiation on the immune system in people is extremely limited. Therefore, it is not possible at the present time to really estimate the consequences of increasing UVB exposure for human disease.

So our reasons for concern with this aspect of the ozone problem are, first of all, that changes in the immune system at least have the potential to adversely affect the incidence and severity of infectious diseases and certain cancers.

Secondly, our concern is that we do not currently have enough information to determine whether the known immunological effects of UVB radiation in humans are serious enough to contribute to disease processes.

Let me spend a moment asking the question, well, what do we know about the immunological effects of UVB radiation? The answer is that in laboratory animals, we actually know a great deal. For example, we know that exposing animals to ultraviolet rays makes them unable to reject skin cancers that are induced by sunlight which, in normal animals, would be rejected by the body's immune system.

We also know that exposing a variety of laboratory animals to a single dose of ultraviolet radiation makes them incapable of making certain immune responses to foreign substances that enter the body through unirradiated skin. This systemic effect of ultraviolet radiation depresses the type of immune response that is important in controlling many infectious diseases.

If you ask how much ultraviolet radiation that is in terms of human exposure, that amount of ultraviolet radiation would be received in roughly ten hours of sunlight exposure in Frederick, Maryland on a roof in the middle of the summer. But it doesn't matter how you get the ten hours of exposure.

The other thing that we know about the immunological effects of ultraviolet on animals is that exposing mice to very low doses of ultraviolet, on the order of 10 to 30 minutes of exposure to sunshine, can impair the immune response to foreign substances that are introduced through the irradiated skin.

We think that this happens because certain immune cells that exist in the skin are especially sensitive to ultraviolet radiation, particularly ultraviolet in the UVB range, and are damaged by it.

There is very little information available on the effects on the immune system with regard to infectious diseases. There are two infectious agents that have been studied: One is herpes simplex virus; the other is a parasite called Leishmania. The immune response to both of these agents can, indeed, be modified by exposure to ultraviolet radiation. Both of these agents do cause disease in humans.

We also know, finally, that the growth and spread of malignant melanomas, a particular kind of skin cancer, is accelerated in mice exposed to ultraviolet radiation.

Now, to try to answer that question in humans, what do we know, the answer is that we know very, very little. We know just enough, I think, to be concerned that there may be a problem. We do know that exposing human skin to low doses of ultraviolet light damages immune cells in the skin. We don't know whether this damage alters the immune response to infectious organisms that enter the body through the skin, but based on the animal studies, I think that this is a real possibility.

Second, we know that exposure of people to sunlight on the beach or to tanning salons does decrease some immune reactions. It alters the proportions of some immunological cells in the blood, and it alters the activity of some immunological cells. We do not know whether these immunologic changes are important in skin cancer or other kinds of cancer or infectious diseases.

But if they are, this could certainly change rather dramatically our estimates of the consequences of UVB exposure for human health. So I think that it is essential that we find out three things: One, what are the effects of ultraviolet B radiation on the immune system in people; second, whether or not these effects contribute to the pathogenesis of infectious diseases and the incidence of cancers; and number three, whether these effects on the immune system are preventable or not by using currently available sunscreens.

Thank you very much.

Senator BAUCUS. Thank you, Dr. Kripke.

Dr. Fitzpatrick?

STATEMENT OF DR. THOMAS B. FITZPATRICK, CHIEF, DERMATOLOGY SERVICE, MASSACHUSETTS GENERAL HOSPITAL

Dr. FITZPATRICK. Yes. My name is Dr. Thomas Fitzpatrick. I am a physician, and chief of dermatology at the Massachusetts General Hospital in Boston and Chairman, Department of Dermatology Harvard Medical School.

I am very happy to have this opportunity to speak to you about the problem of ozone depletion and human health effects, more specifically, skin cancer, which is more easily quantified than any other health effect.

We have a mixed population of susceptible people, there are the three types peoples in the world; brown, white and black. The persons that are affected by the ozone depletion will be the white people. The brown and black people do not have any damage from UV on their skin.

It is virtually unheard of to see very significant amounts of melanoma in the brown and black population. For example, in Bombay, India, the incidence of melanoma is 0.5 per 100,000, whereas in Brisbane, Australia, in the white population, it runs over 40 or 50 per 100,000.

We are speaking about a special kind of UV which is invisible. This invisibility makes it very tricky, because it is not only invisible but it is not perceptible; it is unlike heat. It doesn't give any warning signal. Even for the acute effects, such as a sunburn, are delayed, and comes 20 hours later. We are speaking about UVB, which is, if you look on my testimony on figure 1, you will see the spectral change, the spectrum of the sun. UVB is only one portion of what is emitted from the sunlight.

The theory of ozone depletion increasing UVB intensity, that is the part of the sunlight that gives you sunburn, gives you skin cancer, gives you perhaps aging changes, this idea was first aired in 1970 on Capitol Hill in a press conference held by Senator William Proxmire of Wisconsin.

At this time, it was felt that this had been kind of a hyped up way to get people to stop the SSTs from going forward, and you remember at that time the worry about Concorde and SST. As a result, a special committee of the National Academy of Sciences was created.

The first committee looked at the environmental impact of stratospheric flight.

The stratospheric problem with respect to perturbation by SSTs almost disappeared, because even the sign (+ or −) changed after awhile. It wasn't clear there would be any change in ozone, but it stimulated scientists to study the problem of skin cancer. Not really much had been known about skin cancer. This was the first attempt by the scientific community to get quantitative information on non-melanoma skin cancer.

At the end there was not much agreement that melanoma was related much to UVB. There was a quite clear agreement that UVB was a definite factor in the increase in the production of non-melanoma skin cancer, basal and squamous cell.

With the ideas coming forth on the halocarbons, there was another committee appointed, and I served on this committee also. This was headed by Prof. John Tukey of Princeton. That was a superb study in which there was very clear indication that increase in melanoma would be a problem and, if you will in the testimony at figure 2, you will see a diagram which was the most convincing of the testimony that UVB had something to do with melanoma. We notice that in this diagram, there are some 731 melanomas. There is a clear indication on the doubly covered areas of the body that there is a sparing of the localization melanomas, of the origin of melanomas. As a result of this NAS document, FDA banned the aerosol propellants in 1978 or so, within a few weeks after the report appeared.

Melanoma has been a real problem in the past two decades, but we cannot attribute the increase in melanoma incidence and mortality, for example, a 340 percent increase in the last decade in the southwestern part of the United States, to ozone depletion. We have just heard here that there probably isn't any ozone depletion.

But some rather important facts have come out which indicate that melanoma is not only probably related to UVB, but it is a disease which is precipitated in youth. In other words, in the important epidemiologic studies from western Australia in which case control studies have been done, and in which 511 melanoma patients and they a age/sex match population is compared. It becomes clear that the individuals who develop melanoma seem to have something happen to them before the age of 15.

So this early exposure sets the stage, even though the melanoma may not come on for 10 or 15 or 20 years later. The people migrating to Australia, for example, at age 15, have one-fourth the incidence of melanoma of the people who are born there. I think the most important thing that has happened in the last decade since this whole business was started by Senator Proxmire is the realization that we really have a serious problem with respect to the increasing incidence of melanoma. If you will turn to table 1 and table 2, you will see the rather astounding data that was published in the New England Journal in the fall of 1986, which indicates that for the ages of 30 to 49, melanoma is the second most prevalent tumor in males and that in the ages of 50 to 59, it is the fourth most prevalent tumor.

We really already have a problem with melanoma, and with ozone depletion, this would increase even more, Therefore, thousands of cases would be added on to what is already an existing burden.

Senator **Baucus**. Could you please sum up your testimony?

Dr. **Fitzpatrick**. Yes. I would sum up to say that to pollute the stratosphere with ozone depleting chemicals is an act of destruction causing death and disfigurement of major proportions, simply because people cannot and will not change their lifestyle to adjust to an increased ultraviolet intensity.

Thank you.

Senator **Baucus**. Thank you, Dr. Fitzpatrick.

Dr. Lerman.

STATEMENT OF DR. STANLEY LERMAN, PROFESSOR OF OPHTHALMOLOGY, EMORY UNIVERSITY

Dr. **Lerman**. Thank you. I appreciate the opportunity of saying something about the eye.

Most people tend to take the eye for granted, but actually, aside from the skin, of course, the eye is constantly exposed to radiation. This occurs throughout our life, and it is essentially due to the fact that the eye consists of tissues in the anterior portion which are completely transparent and enable the specific wavelengths of light to get to the back of the eye and initiate the visual process.

Obviously, there is now sufficient consensus amongst photobiologists that our long-term exposure to ultraviolet radiation, be it solar ultraviolet or manmade, does cause changes in the cornea, the ocular lens and the retina as the three main areas of concern.

We are all aware of the fact that in the cornea, you can get so-called snow blindness, from the reflection of ultraviolet in the shorter wavelengths hitting the cornea, and this is a relatively painful but self-limited condition. Arc welder's burn is another effect of ultraviolet.

With the longer exposures, of course, one can severely damage the cornea, but because the radiation induced effect causes pain, people will close their eyes and protect themselves that way if they don't have sufficient sense to protect themselves by proper UV absorbing glasses.

The ultraviolet doesn't discriminate as to color or creed, and it can affect anyone's cornea, but of major concern are the longer wavelengths of ultraviolet, not just the UVB, but the UVA, which penetrate into the interior of the eye.

These rays penetrate through the cornea and into the eye and impinge on the ocular lens. I think, if I might use a little show-and-tell here, it would be helpful for people to realize when we speak about certain portions of the eye what I am talking about.

The cornea, obviously, is this tissue in the front. It is clear, transparent, and it is easily replaced by a corneal transplant if any problems occur.

Behind the cornea is a space filled with fluid which is transparent, looks like water, and then you have your ocular lens, which lies back here behind the iris. The ultraviolet radiation longer than 300 nanometers penetrates the cornea almost 100 percent and impinges on the ocular lens. The lens has chemicals in it that initially absorb certain wavelengths of this ultraviolet, and as we get older, most of us develop pigments in the lens which prevent, with age, the ultraviolet from impinging on the retina, which is the nerve tissue in the back of the eye that initiates the photochemical response, and vision occurs.

The problem with damaging the cornea and lens is quite different than with damaging the retina. The cornea can be replaced. The lens can be removed and, if you want, put a plastic lens in there. The retina, once it is destroyed, assures blindness. There is nothing we can do about the retina once you destroy it.

So the ultraviolet radiation in the UVA as well as UVB range can play a significant role in the generation of photic damage. It is one of the major risk factors in cataract formation and can play a role in certain retinal dystrophies and disease processes.

Obviously, if you increase the level of exposure to ultraviolet radiation, you will just increase the risk factor and eventually, we may get ourselves into a situation where we may not be able to see the mess we have generated.

I don't think there is anything further I need say except to point out that we have two eyes; we should be able to see what is happening to us, and aside from seeing, we should have sufficient common sense that even though there is a small potential change in the ozone layer, a potential depletion, with our everincreasing life span (as far as the eyes are concerned) we are heading for serious troubles except that it may generate further income for those people who replace corneas or remove lenses.

It will do nothing for those whose retinas are damaged and destroyed.

Thank you.

Senator **Baucus**. Thank you very much, Doctor.

Dr. Worrest.

STATEMENT OF DR. ROBERT C. WORREST, DEPARTMENT OF GENERAL SCIENCE, OREGON STATE UNIVERSITY

Dr. **Worrest**. Thank you, Mr. Chairman. I am Professor of Radiation Biology, in the Department of General Science, Oregon State University. I want thank you for the opportunity to describe some of the effects of solar UV-B radiation on marine organisms and the marine food web.

Various experiments have demonstrated that UV-B radiation causes damage to the larval and juvenile stages of fish, to shrimp larvae, crab larvae and other small animals and plants essential to the aquatic food web.

These damaging effects include decreases in reproductive capacity, growth, survival, and other functions of these organisms.

In natural marine plant communities, a change in species composition, rather than a decrease in net production, is the probable result of enhanced UV-B exposure. The change in community composition may result in a more unstable ecosystem and would likely have an influence on higher levels of the food web for example, on shellfish and finfish.

A decrease in column ozone would diminish the near-surface feeding season of small invertebrate animals. Whether this population could endure a significant shortening of the surface season is unknown.

This is a brief description of what might happen at the foundation of the marine food web resulting from a decrease in column ozone. At the upper levels of the marine food web the direct effect of UV-B radiation on food-fish larvae closely parallels the effect on the small invertebrate animals.

Information is required on the seasonal abundances and vertical distributions of fish larvae, as well as vertical mixing and penetration of UV-B radiation into appropriate water columns before the effects of incident or increased levels of exposure to UVB radiation can be predicted.

However, results from one laboratory study involving anchovy larvae supported the conclusion that a 20 percent increase in incident biologically damaging UV-B radiation, which is a result of about a 9 percent decrease in the atmospheric ozone column, could result in the death of all of the larvae within a ten-meter mixed layer in April and August after 15 days of exposure.

It followed that about 8 percent of the annual larval population throughout the entire water column could be directly killed by a 9 percent decrease in column ozone.

Fish are of crucial importance in world nutrition, making up about 18 percent of the average world animal protein intake. That figure rises to nearly 40 percent in Asia, where more than half of mankind lives. The people in Japan, for instance, derive about 60 percent of their intake of animal protein from the ocean.

In addition to the direct effects upon the fisheries, it is possible that with less primary production of organic biomass, there would also be an increased mortality in larval fish due to food limitation. And perhaps there would be a synergetic effect on mortality, in that some animals die from direct exposure, some die from lack of food, and some die from the combination of a reduction in food and the weakening from exposure (or are weakened and become outcompeted by other animals for limited food reserves). Research is in progress to determine the extent of these indirect effects.

Thank you, Mr. Chairman.

Senator **Baucus**. Thank you, Dr. Worrest.

Next is Dr. Teramura.

STATEMENT OF DR. ALAN H. TERAMURA, DEPARTMENT OF BOTANY, UNIVERSITY OF MARYLAND

Dr. **Teramura**. Thank you very much, Mr. Chairman. My name is Alan Teramura. I come the to the hearings this morning from a research leave at the University of Hawaii. I am affiliated permanently with the University of Maryland, College Park.

In the next 5 minutes, what I would like to do is try to summarize what we know about the effects of ultraviolet radiation on crop plants and perhaps, if time is allowed, maybe a little bit about the effects on native or natural plant ecosystems.

To date, the scientific community has screened roughly 200 or so species of plants and different varieties of plants, and alarmingly, they found that two out of every three of these seem to show some degree of sensitivity to ultraviolet radiation.

Among the most sensitive plants are members of the pea and bean family, the squash and melon family as well as the cabbage and mustard family. Probably the most sensitive plant that we have identified thus far is cucumber.

Ultraviolet radiation produces a large number of effects, both on plant physiology, that is, the overall vigor of the plant, as well as morphological and anatomical effects. This morning, I hoped to be able to visually show you some of these effects, but unfortunately, because of some technical difficulties, it looks like I am not going to have that opportunity.

In general, we find that plants are typically stunted in growth by ultraviolet radiation. They have reduced leaf areas; generally, they show some degree of chlorosis or mottling. There is reduction in total dry weight of the plant.

There is also generally a change in the partitioning of dry weight into root shoots and leaves. So ultraviolet radiation definitely has profound effects upon these plants.

The effects I just mentioned are very interesting scientifically, although probably a little bit esoteric for the man-off-the-street. Most people probably are more interested in what effect ultraviolet radiation has upon total crop productivity, and unfortunately, the data set to describe that is very limited.

To date, there have only been nine studies specifically designed to study the effects of increased levels of ultraviolet radiation on crop productivity. Of those nine, we can discount three because of technical reasons. They used unfiltered lamp sources which allowed the plants to be exposed to germicide ultraviolet radiation, something quite unnatural in solar sunlight.

Of the six studies that are remaining, three of these were studies that were conducted for a single growing season. I think if you ask any farmer about the validity of a study spanning a single growing season, he would tell you it is not worth very much because of the inherent variability in yield from year-to-year.

Today, what I want to do is briefly describe some of the results of one study on soybeans. This was a 6-year study. The reason why I chose soybean is because in terms of total dry weight, soybeans is probably the fifth most important crop plant in the world behind rice, wheat, corn and barley.

Soybean is the third most important crop plant in the United States, and the U.S. supplies roughly 60 percent of the world's total soybean harvest.

In this 6-year study between 1981 to 1986, we found in four of those 6 years that ultraviolet radiation simulating a 25 percent ozone depletion at College Park, Maryland, which is about 40 degrees north latitude there was, on the average, about a 20 percent reduction in total dry weight of the beans.

In two of the years, 1983 and 1984 specifically, ultraviolet radiation seemed not to have an effect. However, we now know that these two years were characterized by being very hot and dry and plants experienced prolonged long water stresses. We know from comparative field studies as well as laboratory tests, under water stress, the effects of ultraviolet radiation are masked.

If we just examine the absolute yield for 1983 and 1984, the water stress years, what we find is that in control plants, that is, grown without supplemental UV, these plants would have a reduction in a yield by about one-third already.

So in the more "normal" years, 1981–1982, 1985 and 1986, ultraviolet radiation produced about a 20 percent reduction in yield, whereas in the water stress years, the drought years, water stress resulted in about a 60 percent reduction in yield.

There is also some evidence for changes in the quality of that yield. That is to say, reductions in the percentage of protein and a percentage of oils in those UV-irradiated seeds.

To put this 20 percent reduction in yield into some sort of perspective for you, today in the United States, weeds account for roughly 17 percent loss of our gross soybean harvest. Diseases account for about 12 to 14 percent. We lose about 10 percent due to mechanical harvesting losses and insects account for about 3 percent of our yield losses.

So should these data reflect what might happen in the future, then certainly ultraviolet radiation is going to become the single largest source of the yield reductions that we currently know about.

There is also evidence in the literature, although not directly studied in soybeans, that ultraviolet radiation can also alter the competitiveness of plants. In other words, there is a possibility that weediness could increase or weeds out-competing crops. We also have evidence in the literature which seems to suggest that the incidence of plant diseases may increase because of the weakened state of the host that has been irradiated by ultraviolet radiation. In other words, the losses that I indicated earlier could actually become larger under enhanced levels of ultraviolet radiation.

To summarize this, let me just say that the data that I have just presented probably portrays a worst-case scenario. The reason why I say that is because these data are for only one cultivar of the perhaps dozens of cultivars that are currently grown throughout the United States.

Furthermore, the USDA currently has a seed library of over 12,000 soybean lines. We have examined the sensitivity of 50 of those 12,000. So certainly, we have just begun to scratch the surface.

However, in the absence of other detailed data, not only for soybean cultivars, but also for other key crop species such as rice, wheat or corn, I think these data serve to warn us of the potential consequences of the increased level of solar ultraviolet radiation upon crop plants.

Thank you.

Senator BAUCUS. Thank you very much, Doctor.

Dr. Lerman, I understand lots of tests and studies show that there is an increase, say, of skin cancer over the years, melanomas, basal cell and squamous cell and skin cancer as well as problems affecting the eyes and the cornea.

Some say, "Well, gosh, that has nothing to do with the ozone depletion, just because Americans like to get out and sunbathe more and worship the sun. We go to the beach more. We get outside more. Really, that is the cause of increased skin cancer. We are outdoors more. It has nothing to do with ozone depletion."

What do you have to say to that?

Dr. FITZPATRICK. I am afraid I didn't make that clear enough. I have in the testimony, you see, the present melanoma skin cancer epidemic which affects young and middle aged people is not due to ozone depletion. It is due to leisure time, shorter work weeks, more money, more charter flights to the Carribean, as you say, exactly.

But that doesn't change the problem, because with the ozone depletion and more UV, you are going to have radiation in Boston that is equivalent to what is present in Miami, and so you are going to have that much more of the burden of melanoma, skin cancer, aging and et cetera.

Senator BAUCUS. What you are saying is that even though there may be an increased evidence of skin cancer due to increased leisure time, that it is going to increase that much more?

Dr. FITZPATRICK. Right.

Senator BAUCUS. Because of ozone depletion.

Dr. FITZPATRICK. Right.

Senator BAUCUS. Can you give us the sense of a dermatologist or in the field of dermatology, generally, how much more, in your view, will the projections of ozone depletion increase the incidence of various forms of skin cancer?

Dr. FITZPATRICK. I think you received a copy of this document from the EPA, and by the way, I thought they did a superb job with John Hofmann and Terry Yosie and others, and all the staff.

I would never dare to predict the amounts, of increase of skin cancer but you can say, in general that there is supposed to be a several percent decrease in ozone and that equates to, perhaps, a one or maybe two times increase in UVB, and that we are talking about several thousand cases, perhaps 100,000 cases of melanoma and probably several thousands cases of non-melanoma more than what we have now.

Senator BAUCUS. Is it true that even though there are more cases of non-melanoma skin cancer that because a portion of those non-melanoma that have squamous cells can metastasize. Is that the word?

Dr. FITZPATRICK. Metastasize, yes.

Senator BAUCUS. But the fact is, that mortality rate of non-melanoma is as great as non-melanoma just because there are so many more melanoma?

Dr. FITZPATRICK. The mortality rate of melanoma is around 5,000 in the United States. It is about 25 percent of the incidence, which is 26,000 new cases in 1987.

It is about one-fifth of that of people that die of melanoma. There are significant numbers of non-melanoma skin cancer deaths, perhaps in the range of 200,000 to 500,000 new patients.

Senator BAUCUS. Dr. Kripke, what evidence is there of the progression of disease or increased or decreased functions of the immune system, generally? That is, you say there has not been a lot of health effects in humans. Is there any data at all to show there is increased incidence of diseases due to a reduced function of the immune system?

Dr. KRIPKE. No. There is no data of that kind on humans. There is a small amount of data in animals that exposure to ultraviolet radiation, particularly UVB radiation, can increase the severity of certain infectious diseases.

But this is a very new field. These are new observations, and there has not been a lot of time yet to really analyze what the potential effects for humans are.

Senator **BAUCUS**. Are there any studies contemplated or on-going, do you know, that address that?

Dr. **KRIPKE**. Specifically about infectious diseases in humans, I am not aware.

Senator **BAUCUS**. Something that might show if there is any correlation between increased UV doseage and an increase in infectious disease due to deterioration of the immune system in human beings?

Dr. **KRIPKE**. Not that I am aware of.

Senator **BAUCUS**. Dr. Lerman, are there any studies showing increased incidence of damage to the retina over time? That is, there are studies showing that melanoma cancer is going up, skin cancer is going up. Are there any studies that show that damage to the retina is going up?

Dr. **LERMAN**. There are a lot of experimental studies that definitely show that the retina can be seriously damaged by the UVA. Obviously, the UVB, which is of shorter wavelength and higher energy, would cause more damage more rapidly.

The human data is slowly accumulating, which indicates that the retina can be damaged, as well, by UVA, but in order for this radiation to get to the retina, one has to remove the ocular lens, which acts as a filter for this radiation.

So the dangers from UV radiation in general increasing are: One, to enhance the risk factors for more people developing cataracts. This is a cumulative process. It takes years to develop.

Number two, enhance the potential for serious retinal damage in the millions of patients who have had their cataracts out and no longer have their natural filter. So in both respects, a decline in ozone will significantly increase the damage to specific intraocular tissues.

Senator **BAUCUS**. Thank you.

Senator Chafee?

Senator **CHAFEE**. Thank you, Mr. Chairman.

Dr. Kripke, on the bottom of page 1 of your testimony, you say you do not presently know whether increased UVB radiation will adversely affect the functioning of the immune system because you don't have enough information. But it seems to me that in the rest of your testimony, you make a pretty good case for answering that question yes.

I guess you chaired an SAB subcommittee recently that came out with a report?

Dr. **KRIPKE**. Yes, that is correct.

Senator **CHAFEE**. Didn't that say there is reason to believe that UVB radiation has the potential to modify immune responses in humans and that such modifications could conceivably increase the incidence or severity of some infectious diseases?

Dr. **KRIPKE**. Saying that something has the potential to do that is not the same as the statement that it will occur.

Senator **CHAFEE**. Right. I appreciate that. But you have to be cautious as a scientist, and I understand that. We have to function around here on something less than perfect knowledge, and frequently, we do.

Would you say that there is a high probability or a low probability that increased UVB will adversely affect the functioning of the immune system?

Dr. **Kripke**. A high probability. We already know that it will affect the function. What we don't know is the significance of those effects. We know that there are effects on immunologic function in humans from ultraviolet radiation. We just can't assess the magnitude of those effects in terms of diseases.

Senator **Chafee**. I see. On page 5 of your conclusion, you state that sunscreens may not work to protect damage to the immune system. Could you tell us more about that?

Dr. **Kripke**. Yes. This comes from a very new study that was recently published in the Journal of Investigative Dermatology by a group in Australia.

Senator **Chafee**. By sunscreen, what are you talking about, suntan lotion and things like that?

Dr. **Kripke**. PABA-containing sunscreens with an SPF of 15 was what was used in this particular study. The conclusion from that study was that immunological effects that were being measured in humans were not reduced by the use of sunscreens.

This is a new piece of information, and there is some similar information in animal studies, also, that agrees with that conclusion.

Senator **Chafee**. I must say, Dr. Fitzpatrick, those Western Australians are coming down with melanoma at an incredible rate. How do you account for that?

Dr. **Fitzpatrick**. I think it is nature's experiment of taking a white, susceptible population and moving them to a tropical environment and then having them be outside all the time. They are going to get melanoma. This is a good example of what would happen if you were to change the intensity of UVB in Washington to that of Panama.

This is a highly susceptible people, a color of people who do not tan; who were sent out or went out to Australia and populated the Australian with people susceptible to be exposed to UV. Melanoma is the highest rate in the world in Brisbane, Australia. It is around 50 per 100,000.

Senator **Chafee**. I was going to say, it seems to me that in Australia, I spent some time there, so I am rather sympathetic to that country. There are plenty of other places where you have collections of white people who are in that same latitude and not coming down with melanoma to that rate.

Dr. **Fitzpatrick**. In South Africa, there is a high incidence of melanoma among white people. But you realize that the majority of the people in the world are brown or black, and the incidence of melanoma is very low for those people. In South America, India, the Middle East, Mediterrean, Southern Europe, they don't have a problem with melanoma. It is England, northern Europe, the United States, Australia and South Africa. That is where the melanoma occurs, and that is where the white people are living.

Senator **Chafee**. I was just thinking more if you took the white people in those areas, in India, for example, whites in India, would they have the same incidence?

Dr. **Fitzpatrick**. I don't know about that. I don't think there have been enough that have been studied.

Dr. **Kripke**. There are also studies from Israel, epidemiological studies, showing that populations that migrated from areas that are susceptible populations who live now in the Middle East also have a higher incidence of melanoma.

I think the observation is not unique to Australia. We also see it in Texas, where there are collections of people with Celtic backgrounds and are fair skinned who have a high incidence of both melanoma and non-melanoma skin cancer.

Senator **Chafee**. It is depressing. I guess the other questions mostly have been asked.

This is to everybody here. Is there a threshold level, an acceptable level of ozone depletion?

Dr. **Kripke**. No.

Dr. **Fitzpatrick**. No.

Dr. **Lerman**. No, not as far as I'm concerned.

Dr. **Worrest**. I will reiterate that. No. Some experiments have been carried out where organisms (marine organisms or other small organisms) can tolerate current levels of exposure to UV-B radiation, and if that level does increase slightly, it does seem to cause, in many cases, a precipitous decrease in the survival of these organisms. So many of these organisms exist on a threshold right now or are currently under stress, and any further increase in exposure to UV-B radiation would cause further damage.

Senator **Chafee**. Dr. Teramura?

Dr. **Teremura**. I would also have to say that probably no, there probably are no thresholds.

Senator **Chafee**. Thank you.

Mr. Chairman, I am delighted that you had these witnesses and this panel, and all of them contributed. I think it is very helpful to have a panel of witnesses who dealt with the food chain, because this goes way beyond human health. This goes on to affect the human, our capacity to survive and having enough to eat.

So I was particularly interested in Dr. Worrest and Dr. Teramura, plus all the other doctors, those gathered here. I want to thank you all for coming. You have come from some distance. I appreciate it.

Senator **Baucus**. Thank you, Senator.

I have a question on sunscreens. Do sunscreens help prevent skin cancer, or how is the utilization of sunscreens going to affect ozone depletion?

How does ozone depletion affect sunscreen use? Can sunscreens block out the incidence of skin cancer, even with ozone depletion?

Dr. **Fitzpatrick**. I have to give a scientific answer, which would say that we really don't have any data quantitative data to give to you, like "x" thousands people in a case control study will use sunscreens or didn't use sunscreens but there is a general feeling among dermatologists that sunscreens have contributed very much to the improvement of the statistics with regard to the incidence of skin cancer in the non-melanoma skin cancer in the last 5 years or so.

We didn't have any effective sunscreens prior to 1968. That was when they were really first studied and new effective sunscreen formutlations were produced. A sunscreen, Senator Chafee, is a chemical solution that screens out the UV-B perhaps 85 to 95 percent. I think that everyone would say that we see less damage in patients in the last decade who have consistently used sunscreens.

Senator **Baucus**. Why would sunscreens block out UVA's and UV-B's effects that might cause skin cancer but would not have an effect on the immune system? I don't understand that difference.

Dr. **Fitzpatrick**. There is a possibility that enough was let through—it isn't a 100 percent screen—to not really affect the immune system or to affect the immune system, but was enough to protect the outer layer of the epidermis from being damaged by the sun, whereas this particular layer is down deep in the lymphocyzes in the dermis, and maybe the dose responses are much more sensitive on the immune system than they are on the epidermis.

Senator **Baucus**. Dr. Kripke, do you care to respond?

Dr. **Kripke**. Yes. I think there are two possibilities. One is, as Dr. Fitzpatrick says, that you may need less ultraviolet to do immunological damage than you need to get skin cancer. The other possibility is that the exact wavelengths of ultraviolet light that produce skin cancer and those that produce immunological damage may be different, and that also could account for the difference.

Senator **Chafee**. Could I ask Dr. Lerman a quick question? I will get a little free advice here.

Is there any type of glasses that one should wear to reduce the risk? We have talked about sun shields, and in your area, what is a good sun shield?

Dr. **Lerman**. Yes. Most commercial sun glasses really cannot protect you against all ultraviolet radiation that you are exposed to. But there are specific UV absorbing spectacles on the market which are extremely effective and remove 99-plus percent of all the ambient ultraviolet radiation, and as long as you wear them, you will not have any further photo chemical changes within these ocular tissues that are particularly susceptible, except that you have to remember that if you want complete protection, wear them with a goggle type so that reflective radiation won't come in, as well. If you try to wear goggles all day long outside, you might not be very happy.

Senator **Chafee**. I am going to take some risk and drop the other shoe. Will you tell us how we know the difference? How do we know the good ones from the bad ones. In the secrecy of this room, you can even tell us what brands.

Dr. **Lerman**. Very subtlely; you just take a lens and give it to someone who has a spectrophotometer and have a test conducted.

Otherwise, if you don't have a friend with a spectrophotometer in his home, you have to rely on and wait for the bureaucracy and the FDA, and there is some movement there, to get the manufacturers to lable their sunglasses as to whether they are for cosmetic use or for specific purposes and the percent of UV they transmit or absorb.

I am hopeful that within the next 3 to 5 years these labels will be required in all the States. I believe a bill was introduced in New York State to start that. So then the consumer will know.

Right now, the consumer has no way of knowing, and most of the adds are quite misleading when they talk about UV protection.

Senator **CHAFEE**. Let me phrase it this way: What model and kind do you wear?

Dr. **LERMAN**. I wear this here, which is just ordinary window glass, and it has been coated to reflect all ultraviolet infrared radiation. Unfortunately, the manufacturer who made these went out of business because of lack of interest.

There are available actually at least three or four different manufacturers who are making good UV protective lenses. Any optician should be able to provide you, or any optometrist, as well as any ophthamologist should be able to provide you with them. I have strongly recommended that all people who have had their cataracts removed should wear those types of corrective lenses to protect themselves.

Senator **CHAFEE**. No one will accuse you of tossing around carelessly endorsements for products.

Senator **BAUCUS**. I want to ask you, Dr. Lerman.

Dr. **FITZPATRICK**. Senator Chafee, this is a pair of such glasses.

Senator **CHAFEE**. Who makes them? I am trying to get the make.

Dr. **LERMAN**. I will be happy to give you the name of the maker. I have no financial interest in any of them except I have occasionally sold some of them short.

Senator **CHAFEE**. Okay.

Dr. **FITZPATRICK**. The name is UVA 400, Orcalite.

Dr. **LERMAN**. UV 400 is one. Univis; and Silor is the third that make these lenses, and they can include the prescription that you require or not, if you don't need it.

Senator **CHAFEE**. Everybody has their pencil out writing.

Dr. **LERMAN**. They do charge extra for these types of glass.

Senator **CHAFEE**. What good are the sunglasses if they don't exclude it?

Senator **BAUCUS**. I understand it, sunglasses are worse.

Dr. **LERMAN**. In some respects, if you happen to have blue eyes, like myself, and you wear sunglasses, which remove a large portion of the visible radiation and do not completely remove the ultraviolet radiation, then what happens is your pupil gets larger, and if you enlarge the pupil, you markedly increase the amount of ultraviolet getting into the lens and the back of the eye.

Senator **CHAFEE**. Well, Mr. Chairman, I will say this. If you stick around this committee too long, you will get discouraged. Today, we better not not go outside because of UVB and UVA will get us and get our eyes. Last week we had testimony that the indoor air is terrible; radon is sweeping up through. We are done for. We will have to take our chances in life, stay away from western Australia and do the best we can.

Thank you all very much for coming.

Senator **BAUCUS**. We all thank you very much, and the hearing record will be open for 10 days for you to answer any written questions we may have. Thank you all very much.

Senator **CHAFEE**. Excellent job, all of you.

[Whereupon, at 12:45 p.m., the subcommittees were recessed to reconvene Wednesday, May 13, 1987.]

[Statements submitted for the record follow:]

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Information 87/10
6 May 1987

"Nowhere to hide"

STATEMENT BY DR. MOSTAFA K. TOLBA
EXECUTIVE DIRECTOR
UNITED NATIONS ENVIRONMENT PROGRAMME
TO THE AD HOC WORKING GROUP OF LEGAL AND
TECHNICAL EXPERTS FOR THE PREPARATION OF
A PROTOCOL ON CFCs TO THE VIENNA CONVENTION
FOR THE PROTECTION OF THE OZONE LAYER
(Vienna Group) - Third Session
Geneva, 27 April 1987

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For use of information media - not an official record

Mr. Chairman, Ladies and Gentlemen,

It is a great pleasure for me to be with you here today. I sincerely hope you will take as a clear indication of how much importance we in UNEP and me personally attach to your work.

When the meeting in Vienna concluded I was concerned.

I was concerned that the scientific community appeared divided on the issue of ozone. I was concerned that European and American delegates left the meeting with quite different predictions about the rate of ozone depletion. I was concerned that they left with different opinions about the regulatory measures necessary to protect human health and various aspects of the environment. And most of all, I was concerned that scientific debate on these issues would be used as an excuse for doing nothing.

Mr. Chairman,

UNEP's position has always been clear. So long as there is a prima facie case against a chemical, we must urge caution. It is not good enough to play with the chemical make-up of the atmosphere and just assume that all will be well. It is not good enough to assume the best until the worst is known. The future of the planet cannot be gambled away.

I am now pleased to say that consensus among the scientific community is confirmed, and the path towards international regulation is clear.

The American and European modellers who left the Vienna meeting initially appeared divided on the fate of the ozone layer. In the USA they prepared a paper showing the possible impact of different control strategies. Their results apparently showed that only a significant reduction in the production of chlorofluorocarbons would protect the ozone layer from major damage. European delegates had queried a number of the assumptions in that model. Their own models, it was claimed, showed that limited regulatory action would be sufficient.

UNEP brought together the major ozone modellers in Wurzburg in the Federal Republic of Germany. Modellers were asked to come to the meeting each having applied their models to nine different scenarios of Chlorofluorocarbon control ranging from moderate limitations to severe restrictions.

Results were compared. They were very similar. The degree of discrepancy between the models was - for the most part - smaller than the margin of error in each particular model.

No longer can those who oppose action to regulate CFC release hide behind scientific dissent. I might add that that line was always a charade. Scientific debate and disagreement has always - and will always be - a normal part of the quest for knowledge.

There has always been a consensus that, when we are talking of the future of the earth's atmosphere, we are better safe than sorry. It is only within that context that debate has taken place.

Let me now briefly review the findings of the Wurzburg meeting.

First, the modellers on both sides of the Atlantic agreed that, under given assumptions for trace gas emissions, all regulatory strictures currently being examined will result in some degree of ozone depletion. Ozone depletion is here. What we are talking about is how great that depletion will be.

Second, all modellers agree that regulatory action that covers only CFCs 11 and 12 would fail to address the problem of ozone depletion in its entirity. Models showed, for instance, that CFC 113 will play a significant role in the ozone equation, as will Halons 1211 and 1301. Regulations that fail to take into account these substances may not be adequate.

Third, all of the modellers agree that even if ozone depletion is restricted to minimum levels, changes in the vertical distribution of ozone will still occur - less in stratospheric ozone, but more in the lower atmosphere. This inevitable change will contribute to the expected future 'greenhouse warming' and its attendant problems of rising sea level, changing agricultural patterns and other environmental risks.

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The fourth finding is perhaps the most significant. Modellers agreed that the rate of ozone depletion depends on the control strategy chosen. Modellers agree that with no control the ozone layer would be modified to an extent which will certainly increase human cancers, will probably affect agricultural production, and climate change.

Strong regulations on the other hand will certainly reduce those risks.

That is the consensus.

Modellers were confident enough of their findings that they took the extraordinary step of passing the preliminary results to representatives of the Chemical Manufacturers' Association. By and large the representatives of industry were receptive to the models, though, like us, they hoped that a more detailed analysis of CFC production and use in the Third World would be forthcoming. This is one of the points that clearly need focussing. There is very little agreement as to how much rates of release will increase in these countries.

The United States Environmental Protection Agency, for instance, forecast a major increase in production and use in the third world. Other economic analysts predict a less dramatic increase.

Another point: The scientific community cannot discount the possibility that new technologies might emerge. One day new technologies for CFC recovery could allow for an increase in production and use, without bringing comparable increases in ozone-depleting releases. However, scientists would not second guess the future.

And a third point. The Modellers did not claim to fully understand the chemistry and physics of the atmosphere. They specifically said that any measures taken should be flexible enough to be altered should changes take place that were not fully understood or explained at the time of agreement. They pointed to the ozone hole over the Antarctic as an example.

Ladies and Gentlemen,

Where do we go from here?

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UNEP has two proposals.

The first is that we act on what we do know. The second is that we expand our knowledge into areas we do not know.

We know that the ozone layer is under threat from CFC emissions. We know that the consequences could involve the future of life on earth. We know that we can reduce the risk by reducing CFC and Halon emissions. There is not a serious scientific investigation in the world today that refutes these facts.

Our course of action should be clear. CFC production must be limited. Halon production must also be limited. UNEP wants to see an international agreement reached here whereby rates of production and use in the developed world and any major producers or users in the Developing Countries will be frozen right now at current levels and reduced to a very small fraction of the frozen levels within the next decade.

Let me put this in more concrete terms. What I envisage is:

1. The protocol agreed here in Geneva.

2. The protocol adopted and signed in the summer or early autumn of this year.

3. I sincerely hope that the parties to the Convention ratify the Ozone Convention during 1987 and early 1988 to come into force in 1988, and that the Protocol itself also comes into force in 1988.

4. We want to see a complete freeze on production and use at 1986 levels affected in 1990, 2 years after the protocol enters into force. After that, every 2 years we achieve a reduction of 20% which would mean we reach zero by the year 2000.

5. In the meantime I am proposing that there would be a rigorous scientific review every 4 years from the time of entry into force of the protocol, i.e. the first such review would be in 1992 and the second in 1996. Such scientific review is to confirm or otherwise the need for further reduction.

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That is my concrete proposal: the protocol coming into force in 1988; freeze on production and use in 1990; first 20% reduction in 1992 and another 20% every two years thereafter.

In most of the third world Countries - where CFC use is limited but growing - monitoring of CFC production should continue. Provision should be made in the agreement to further regulate third world production if it too becomes a major element in the ozone equation. Provision should also be made in the treaty for the restrictions to be lifted in the unlikely event of CFCs and Halons being given a clean bill of health.

The search for substitutes should continue. Investigation into the use of CFC 134a and other substitutes should be accelerated. Research into recovery technologies should be accelerated. Research into the physics and chemistry of the atmosphere should continue at its present rapid rate. Aided by the extraordinary pool of talent we have all over the world, our knowledge will surely grow.

Ladies and Gentlemen,

For the first time, the path to regulation is clear. The time for rational and responsible action is here.

It is possible - indeed, the best scientists in the field say that it is almost certain - that CFCs have the capacity to cause unmeasurable damage to our planet. If we believe that we cannot risk that damage, then we must act. If we believe that life must continue unthreatened by changes in the atmosphere, then we must act. We must not gamble on the off-chance that maybe - just maybe - all will be well.

For the first time in my experience the world has a chance to act before disaster strikes. And remember, if we mess up this planet, we can't go and look for another.

Ladies and Gentlemen,

The evidence is here. Let's not gamble with the only planet we have.

Thank you.

Testimony of F. Sherwood Rowland, Professor of Chemistry,
University of California, Irvine, May 12, 1987
Senate Committee on Environment and Public Works
Sub-Committee on Hazardous Wastes and Toxic Substances
Sub-Committee on Environmental Protection

The scientific problem of ozone depletion by chlorofluorocarbon compounds (CFCs) was first described in June 1974 in the article "Stratospheric Sink for Chlorofluoromethanes--Chlorine Atom Catalysed Destruction of Ozone" by M. J. Molina and F. S. Rowland [Nature 249, 810 (1974)]. The abstract of this paper summarized its content in three sentences:

"Chlorofluoromethanes are being added to the environment in steadily increasing amounts. These compounds are chemically inert and may remain in the atmosphere for 40-150 years, and concentrations can be expected to reach 10 to 30 times present levels. Photodissociation of the chlorofluoromethanes in the stratosphere produces significant amounts of chlorine atoms, and leads to the destruction of atmospheric ozone."

An extended description of this work was submitted three months later to the sponsoring agency, the U.S. Atomic Energy Commission, and appeared soon after as a review article: "Chlorofluoromethanes in the Environment", by F. S. Rowland and M. J. Molina [Rev. Geophys. Space Phys., 13, 1 (1975)].

The statements in the Nature abstract are now generally accepted in the scientific community as factual descriptions of the behavior of chlorofluorocarbons in the atmosphere: These molecules do survive for many decades in the atmosphere; do rise into the stratosphere, and are decomposed there by solar radiation; do release chlorine atoms, and these atoms then do cause ozone depletion there. The yearly release of the molecules CCl_3F and CCl_2F_2 to the atmosphere doubled every five to seven years for two decades into the mid-1970s, and then leveled off after regulations on their use as aerosol propellants were put into place in the U.S., Canada, and Scandinavia. In the past several years, the yearly emissions of these compounds have again begun to increase.

Some comments: "First, the evidence reviewed in this report suggests that the theory of humanly induced chemical change in the stratosphere remains valid." ["Causes and Effects of Changes in Stratospheric Ozone: Update 1983", National Academy of Sciences, 1984, p. 14];

"Recognizing the possibility that world-wide emissions and use of fully-halogenated chlorofluorocarbons (CFCs) and other chlorine-containing substances can significantly deplete and otherwise modify the ozone layer, leading to potentially adverse effects on human health, crops, marine life, materials and climate..." [Resolution on a Protocol Concerning Chlorofluorocarbons, from the Vienna Convention for the Protection of the Ozone Layer, 1985];

"Let me summarize what we have learned to date. First, the basic elements of the ozone depletion theory proposed by Rowland and Molina have been verified by observations." [Dr. Joseph Steed, "Freon" Products Division, DuPont Company, at the 1987 Conference on CFCs and Ozone Protection Programs, Washington, D.C., March 24-25, 1987.]

The scientific description of the chlorofluorocarbon/ozone problem depended strongly on the 1971-1974 Climatic Impact Assessment Program of the Department of Transportation which had investigated the potential impact of high altitude supersonic transport aircraft on stratospheric ozone. The existence of a chlorine-induced chain reaction capable of removing stratospheric ozone had been discovered by Stolarski and Cicerone in 1973 while considering the release of hydrogen chloride during the planned future rocket launchings of the Space Shuttle. The potential ozone-depleting effects of chlorine from the chlorofluorocarbons were quickly confirmed in reports by Cicerone, Stolarski and Walters [Science, 185, 1165 (1974)], Crutzen [Geophys. Res. Lett., 1, 205 (1974)] and Wofsy, McElroy and Sze, [Science, 187, 535 (1975)], and investigating committees were organized both by the U.S. government and by the U.S. National Academy of Sciences.

The 14-agency Federal IMOS Task Force reported in June 1975, "The task force has concluded that fluorocarbons released to the environment are a legitimate cause for concern. It also has concluded that unless new scientific evidence is found to remove the cause for concern, it would seem necessary to restrict uses of fluorocarbons-11 and -12 to replacement of fluids in existing refrigeration and air-conditioning equipment and to closed recycled systems or other uses not involving release to the atmosphere." [p. iii, Introduction to "Fluorocarbons and the Environment", Report of Federal Task Force on Inadvertent Modification of the Stratosphere (IMOS)].

The National Academy of Sciences presented two reports in September 1976, a detailed study of the atmospheric science involved, "Halocarbons: Effects on Stratospheric Ozone", and a more general consideration of the entire problem, including the associated health and biological consequences, "Halocarbons: Environmental Effects of Chlorofluoromethane Release". The latter document stated in its Executive Summary (p.7): "Selective regulation of CFM uses and releases is almost certain to be necessary at some time and to some degree of completeness. Neither the needed timing nor the needed severity can be reasonably specified today..."

The scientific community had thus immediately begun an intense program of evaluation of various aspects of the chlorofluorocarbon ozone problem, a program which is still very actively in progress. The industrial community had also been alerted in 1975 and 1976 that some of the chlorine-containing molecules with particular technological advantages had negative stratospheric effects sufficiently serious that their continued usage in large quantity was in serious doubt. These limitations were made very evident in October 1976 through the announcement by several federal agencies (E.P.A., F.D.A., C.P.S.C.) that the uses of certain chlorofluorocarbons as propellant gases in aerosol sprays were going to be severely reduced within the next 18 months. Many investigations were initiated then into substitutes not only for CFCs as aerosol propellants, but also as refrigerants, in foam-blowing, in the cleaning of electronic components, etc. The National Academy of Sciences has issued subsequent reports in 1979, 1982 and 1984, and NASA has also presented several reports, the most recent a three volume study, "Atmospheric Ozone 1985", conducted in collaboration with the World Meteorological Organization and released one year ago.

The primary ozone depletion concerns over the past decade have involved delivery to the stratosphere of large quantities of chlorine (or bromine) atoms in molecules inert toward chemical or physical removal processes in the lower atmosphere. Usually the chlorine atoms have been combined with fluorine atoms in chlorofluorocarbon compounds which are either gases or liquids with low boiling points, and which behave as gases after release to the atmosphere. (The fluorine atoms from chlorofluorocarbon molecules have only a very small potential for depletion of stratospheric ozone.)

Ever since 1974, the chlorine-containing compounds have been divided into two categories with respect to capabilities for ozone depletion:

(1) the perhalo saturated chloro and bromo compounds, i.e. not containing hydrogen or carbon-carbon multiple bonds, but often containing fluorine as the other element attached to carbon. These compounds are the major threats for ozone depletion because they are not destroyed by processes in the lower atmosphere, and therefore survive for many decades, eventually drifting into the stratosphere where they can be decomposed by solar ultraviolet radiation. The most important compounds in this category are the widely used CCl_3F (CFC-11), CCl_2F_2 (CFC-12), CCl_2FCClF_2 (CFC-113), $CClF_2CClF_2$ (CFC-114) and carbon tetrachloride, CCl_4.

(2) chloro compounds which do contain hydrogen or carbon-carbon multiple bonds. The compounds in this second group are susceptible to oxidation and destruction in the lower atmosphere, greatly reducing their individual threat to ozone in the stratosphere. Molecules in this category usually contain either hydrogen atoms or carbon-carbon multiple bonds or both, and some are already in major usage: $CHClF_2$ (CFC-22), CH_3CCl_3 (methylchloroform), $CHCl{=}CCl_2$ (trichloroethylene) and $CCl_2{=}CCl_2$ (perchloroethylene). Studies have confirmed that these molecules, although certainly detectable in the atmosphere, do not accumulate to the same extent as the much longer-lived compounds in the first group.

These compounds are not without stratospheric ozone depletion capabilities, but the threat is substantially less than from compounds in the first group. Other members of this group are compounds not yet in major production, but which might be acceptable substitutes in technological usage, such as $CHCl_2CF_3$ (CFC-123), $C_2H_3ClF_2$ (CFC-142b) and $CClF{=}CClF$.

Important related compounds not included in either of the groups above are the hydrofluorocarbons, which have the dual advantage of containing hydrogen so that the atmospheric lifetime will not be unduly long, and of not containing chlorine or bromine--and therefore offering essentially zero threat of ozone depletion from that small fraction of the molecules which would reach the stratosphere. Long range solutions to technological substitutions may well come from this class of molecules. An important example is CH_2FCF_3 (FC-134a) which has many physical properties quite similar to those of CFC-12.

The original theory of ozone depletion by chlorofluorocarbon compounds was put forward at a time when there were no measurements of chlorine-containing molecules anywhere in the stratosphere, and was based upon knowledge of atmospheric composition and average transport dynamics, plus information about the photochemical and chemical properties of the chlorofluorocarbon compounds as measured in the laboratory. In the intervening decade, numerous measurements have confirmed the presence of many chlorine compounds (HCl, ClO, Cl, $ClONO_2$, etc.) in the stratosphere. The quantitative aspects of ozone depletion were first developed in terms of global averages, with an estimate that the long-term steady state loss of ozone would probably lie somewhere in the range from 7% to 13% if world-wide emission of CFCs were to continue a constant rate. These quantitative estimates have varied appreciably over the succeeding 13 years as new or more accurate information became available about the atmospheric processes involved.

After first examining all of the possible processes which might remove molecules such as CCl_3F or CCl_2F_2 in the lower atmosphere and finding none of any importance, the lifetimes for each were calculated on the assumption that stratospheric losses would be the only important sink for either. In 1974, Molina and I calculated that the average atmospheric lifetimes for CCl_3F and CCl_2F_2 were very long, falling into the range from 40 to 80 years, and from 75 to 150 years, respectively. One of the major scientific disputes between 1974 and 1983 centered on the original Rowland-Molina assumption that the only major destruction location for the CFCs is in the stratosphere. Questions were raised about the assumption that removal processes in the lower atmosphere, usually described as tropospheric sinks, were of negligible importance for CCl_3F, CCl_2F_2 and other perhalo saturated chlorofluorocarbons. Many possible chemical or physical processes were postulated to be very important--freezing out on Antarctic snow; decomposition in contact with hot desert sand; attack by positive or negative ions in the atmosphere--only to be found of negligible importance when carefully evaluated for the real atmosphere.

Another approach to the tropospheric sink problem treated the possibilities either that a major removal process existed which had not yet been singled out for specific investigation, or that a substantial number of lesser processes might, when added together, represent an appreciable alternative to stratospheric destruction. The ultimate test of such undiscovered tropospheric sinks is whether or not the compounds of interest disappear from the atmosphere more rapidly than can be accounted for by stratospheric processes alone. While such "missing" amounts of chlorofluorocarbons were reported in a series of publications, this global CFC accounting was eventually proven to be faulty because of a gross underestimate of the amounts of CFCs in the southern hemisphere and in the northern hemisphere tropics.

The observed concentrations of the CFCs have mounted steadily, and the total amount of chlorine bonded to carbon in the troposphere has risen from 0.7 parts per billion by volume (ppbv) in 1950 to 1.0 ppbv in 1970 and more than 3.5 ppbv in 1987. Careful comparison of the amounts of these gases emitted to the atmosphere to date and the amounts still remaining in the atmosphere suggests lifetimes of about 75 years for CCl_3F and 120 years for CCl_2F_2, fully consistent with the conclusion that no important tropospheric sinks exist for either. By analogy, atmospheric lifetimes of a century or more are now indicated for other perhalo saturated chlorofluorocarbons such as CCl_2FCClF_2. A 120 year average lifetime, without any intervening major changes in the atmosphere, means that 90% of the molecules now in the atmosphere will still be there in 2000 A.D., 39% in 2100 A.D., 17% in 2200 A.D. and 7% in 2300 A.D. Even without any further emission of CCl_2F_2--and releases are occurring daily all over the world sufficient to average about 400 kilotons annually-- appreciable concentrations of CCl_2F_2 will survive in the atmosphere for the next several centuries.

The chlorofluorocarbons themselves are quite inert, and do not interact chemically in the atmosphere until they are dissociated by the absorption of solar ultraviolet radiation. This dissociation, however, releases highly reactive atomic chlorine, which initiates the ClO_x chain reaction in which Cl reacts with O_3 to form ClO, and ClO reacts with O atoms to form Cl again. This two-stage chain is completed in about one minute under most conditions in the sunlit stratosphere, and can account for the destruction of as many as 100,000 molecules of ozone before the chain eventually drifts into the lower atmosphere and is finally stopped. Because the abundance of the oxygen atoms needed for the second reaction is much higher in the upper stratosphere than at lower altitudes, the depletion of ozone by the ClO_x chain has always been calculated to be most effective in the upper stratosphere, with the highest percentage removal of ozone expected near 40 kilometers (25 miles) altitude.

The 1984 National Academy of Sciences report on ozone depletion stated, "As has been the case for a number of years, photochemical models calculate that the largest relative local change in ozone for continued release of CFCs should occur at an altitude near 40 km. New analyses of observed ozone trends are limited by the reliability of the ground-based Umkehr data, but suggest a decrease of ozone concentration at this altitude over the past decade. The magnitude of the observed decrease, approximately 3 percent, is uncertain, but it is in agreement with current theory. Models suggest that the percentage changes in ozone near 40 km are primarily due to chlorine, produced by the photolysis of CFCs." (p. 10 of Summary, "Causes and Effects of Changes in Stratospheric Ozone: Update 1983"). The 1986 WMO-NASA report similarly stated: "All models with all scenarios predict that continued release of CFC's 11 and 12 at the 1980 rate will reduce local ozone at 40 km by 40% or more." (p. 18, "Atmospheric Ozone 1985", WMO-NASA Global Ozone Research and Monitoring Project--Report No. 16) and "Ozone trend estimates from 13 Umkehr stations indicate statistically significant negative trends from 1970 to 1980 in the middle stratosphere that are in substantive agreement with results from one-dimensional numerical models..." (p. 20).

In summary then, all of the atmospheric model calculations for the past 13 years have indicated that substantial losses of ozone should be inflicted around 40 km altitude by the chlorine atoms released in the decomposition of chlorofluorocarbon compounds; ozone depletion from the compounds already released should have produced an observable change at that altitude between 1970 and 1980; and the available scientific instruments capable of such a measurement have indicated a loss consistent with that expected on the basis of the calculations. It should be emphasized that these measurements of ozone loss in the upper stratosphere by the Umkehr technique are based largely on data collected by stations geographically located in the north temperate zone, i.e. the U.S., western Europe and Japan, and therefore represent changes in the upper stratospheric concentrations of ozone directly above those locations. Because upper stratospheric ozone is an important absorber of solar UV radiation, the selective loss of ozone there will reduce the heating effects of such absorption, with a consequent drop in the temperature of the upper stratosphere. Eventual decreases as large as 20°C are calculated in the 40-50 km altitude range from continued release of CFCs to the atmosphere.

Some of the most important developments in the chlorofluorocarbon ozone problem over the past dozen years have involved more and more complex descriptions of the atmosphere:

(a) Additional chemicals not previously considered important such as $ClONO_2$ and HO_2NO_2 have been included, and additional chemical reactions have been considered for molecules already known to be important;

(b) General global average one-dimensional (1-D) models have largely been replaced with two-dimensional models which investigate variations versus both latitude and altitude;

(c) The effects of simultaneous increases in the concentrations of other trace gases have been included in the atmospheric models;

(d) Heterogeneous chemical reactions, a particularly important class of molecular change, have been postulated to be of stratospheric importance, at least under some particular circumstances.

None of these changes have appreciably affected the consensus scientific opinion that additional chlorinated compounds in the lower atmosphere will lead a few years later to more ClO_x chains in the stratosphere, with accompanying depletion of ozone around 40 km. Several of these changes, however, have had very significant consequences for atmospheric model predictions of future losses in total ozone because of the complicated chemical interactions in the lower stratosphere among the species in the ClO_x chain with those of the NO_x (NO, NO_2) and HO_x (HO, HO_2) chains which are operating simultaneously. For example, the reaction of the important ClO radical with NO_2 to form the temporary stratospheric reservoir molecule chlorine nitrate, $ClONO_2$, removes one reactive species capable of ozone depletion from each of the

ClO_x and NO_x chains. The chlorine nitrate molecule can then be decomposed by the absorption of ultraviolet light, but during its temporary existence the process of ozone depletion by both the ClO_x and NO_x chains is interrupted. Similarly, the development of a direct method for measuring the reaction rate constant for the radical HO_2 with NO demonstrated that the previous indirect determinations were in error by a factor of about 40, and materially changed the conclusions of atmospheric model calculations about both the chlorofluorocarbon ozone problem and about the SST ozone problem. The fluctuations in the predictions from the best current atmospheric models in response to the inclusion of new reactants, new reactions, or re-evaluations of those already in use have been duly reported in the successive N.A.S. and NASA reports.

The real atmosphere is of course three dimensional, and scientists would in principle prefer to be able to predict the future atmospheric changes anticipated for each combination of latitude, longitude and altitude. At present, however, full three-dimensional (3-D) models require more detailed chemical information for complete validation than is yet available, in addition to being computationally much more demanding. The 1-D model calculations typically produce information about the expected vertical variations in the concentrations of various chemicals, including ozone, for a set of conditions appropriate to 30°N latitude averaged over all longitudes. Because experimental observations in the atmosphere have shown that the concentrations of many chemicals are quite similar for any longitude at a given latitude, two dimensional (2-D) models providing estimates for different combinations of latitude and altitude have been developed in the 1980s to provide more detailed information about the geographical structure of the chemical changes being observed and predicted for the atmosphere. The estimates performed with the various 2-D models have shown latitudinal structure in the calculated losses of ozone in the present atmosphere from chemicals already emitted, as well as in future ozone depletions from continued release of CFCs. Several different 2-D models have generally been in agreement that ozone depletion is expected to be larger in the higher latitudes of both hemispheres than in the equatorial regions.

In 1974 the measurements of many atmospheric chemical components were quite limited, and the only major trace gas known to be increasing steadily on a global basis was carbon dioxide, CO_2. Rapid increases in the atmospheric concentrations of several of the organic chlorocarbons were quickly established in the mid-1970s, and those of other molecules such as nitrous oxide, N_2O, and methane, CH_4, have now been shown also to be steadily rising. Furthermore, while only a few SSTs have been flown commercially, the growth over the past two decades in the commercial fleets of subsonic jet aircraft has insured that the yearly amounts of nitrogen oxides emitted from these planes into the lower stratosphere has certainly grown. Therefore, realistic simulations of the changes with time for various chemical species such as ozone must make proper allowance for simultaneous increases in the atmospheric concentrations of several other chemicals in addition to the chlorofluorocarbon compounds.

These increasing complexities in the atmospheric modeling have produced very large variations in the predictions of ozone changes in the lower stratosphere, sometimes showing decreases with resulting large estimates for eventual total ozone depletion, and sometimes predicting actual ozone increases in the lower stratosphere sufficient to offset much of the large losses expected at 40 km in the estimates of total ozone depletion. The original National Academy of Sciences report in 1976 had recognized the magnitude of the uncertainties in such estimates of eventual long-term ozone depletion, and gave a central prediction of a loss of 7%. They, however, also stated that this estimate was not well known at that time, and could vary with increasing knowledge from depletions as small as 2% to as large as 20%. Over the next eight years, the central value of the most recent "best" calculation did indeed fluctuate quite widely, and at various times the central value called for ozone depletions almost as large as 20% and almost as small as 2%. As these long-term central values for ozone depletion varied up and down, the N.A.S. reports continued to emphasize that large uncertainties remained, and that eventual substantial losses in the range of 10% or greater could not be dismissed even when the calculations suggested losses of only a few percent.

All predictions of long-term future ozone changes now require assumed future scenarios for the changes in several trace gases: Will the chlorofluorocarbons continued to be emitted at a constant rate each year? Or will the world-wide usage be reduced by governmental regulation? Or be increased in the absence of any regulations beyond the bans on use as aerosol propellants in North America and Scandinavia?

Will CH_4 concentrations continue to grow at the rate of 1% per year? At what rates will CO_2 and N_2O increase?

From 1974 until 1984 all of the chemical reactions considered in these atmospheric models were homogeneous gas phase reactions, for the very good reason that no chemical reactions of another kind had yet been demonstrated to be important in the stratosphere. Measurements over the past half century have carefully established that homogeneous gas reactions have the extremely important property that experiments in different laboratories are highly reproducible if the temperature, pressure and composition of the gas are precisely controlled. Under these circumstances, scientists can be highly confident that chemical reactions in the real atmosphere will follow the same course as followed by these compounds under comparable conditions in the laboratory. Moreover, the behavior of complex mixtures of gases has been found to correspond to that anticipated from the composite of individual measurements of the different chemical reactions in the laboratory. With homogeneous gas reactions, scientists need to know the complete set of reactants, reactions and reaction rate constants measured in the laboratory, and can then accurately predict the future course of even very complicated systems such as occur in the atmosphere.

The situation is quite different with heterogeneous reactions, chemical changes which occur on various, often irregular, surfaces. In these situations, reproducibility is much more difficult and disagreement can even occur on whether a particular reaction takes place or not. The basic problem is that the various surfaces of particles facilitate chemical reactions to different extents--as with the catalysts used in the commerical cracking of the heavier components of gasoline into more useful smaller fragments. Here, the accumulated wisdom from thousands of laboratory experiments has been that duplication of surfaces and of surface-catalyzed chemical reaction rates is difficult, even with materials of precisely known chemical composition.

Particles of various kinds are well known to exist in the atmosphere, but relatively little is known about their exact chemical composition or the structure of the surfaces, especially for those in the stratosphere. Some particles are introduced by volcanic emissions, and others coagulate in the stratosphere from chemical transformations occurring there. Under these conditions and at least until much more is known about stratospheric particles, duplication in the laboratory of the available stratospheric surfaces is essentially impossible. The general conclusion can then be drawn: If heterogeneous reactions are found to be important in the stratosphere for some chemical changes, then reproducible, precise measurements of the appropriate reaction rates in the laboratory will not be possible for many years, and reliance will have to be placed upon observations of the chemical changes occurring in the atmosphere itself.

In 1984 Dr. Haruo Sato and I began laboratory research on the reactions of chlorine nitrate with water and with hydrogen chloride, and found that both occurred extremely rapidly on all of the normally inert surfaces used to eliminate or suppress surface reactions in such experiments. These reactions convert the chlorine in the temporary reservoir molecules HCl and $ClONO_2$ into other molecular forms of chlorine (Cl_2 and HOCl) which are much more easily decomposed by solar radiation. Drs. Donald Wuebbles and Peter Connell of the Lawrence Livermore Laboratory then tested whether either of these reactions could have a significant influence on future predictions of stratospheric ozone depletion, and found that each of them by itself could cause profoundly greater depletions than were then being calculated with the atmospheric models which contained only homogeneous gas phase chemistry. I presented both the laboratory results of Sato and Rowland and the calculations of Wuebbles and Connell to the Meeting on Stratospheric Ozone which was held in Feldafing (Munich), West Germany, in June 1984. The basic problem then, and now, is how to include such reactions in a quantitatively accurate manner in the atmospheric model calculations. Work at the University of California Riverside has clearly shown that the homogeneous gas reaction rates for chlorine nitrate with both water and hydrogen chloride are much too slow to have any importance in the stratosphere; if important, then they must be taking place via heterogeneous reactions occurring on surfaces of stratospheric particles.

Large losses in ozone during the Antarctic spring were first noticed in 1977 by the scientists of the British Antarctic Survey at their ground-based station at Halley Bay on the Antarctic coast. These depletions became substantially larger during the 1980s, approaching 50% in late September and October in comparison with the concentrations found during the period from 1957 to 1975. These substantial ozone losses have been fully confirmed both by the TOMS and SBUV instruments on the U.S. satellite Nimbus-7, and by Japanese and now U.S. measurements with balloon-borne equipment released from the Antarctic surface. The balloon ascents have also shown that the major ozone losses over

Antarctica are found in the lower stratosphere between 12 km and 20 km altitude, and furthermore show extreme patchiness in the vertical structure of the ozone depletion. The satellite data have been particularly useful because they have provided a daily record of total ozone concentrations over the entire globe since the autumn of 1978. Dr. Donald Heath and colleagues have stated that a global average loss of ozone of several percent took place between 1978 and 1984, with a further decrease to 1986. The largest average losses have been found in the high latitudes of the southern hemisphere, the next largest in the high latitudes of the northern hemisphere, and some loss has been indicated at essentially all latitudes over this time period.

The atmospheric model calculations of 1984 and early 1985--containing only homogeneous gas phase reactions--were unable to reproduce the very large rates of ozone loss found during September over Antarctica. However, when the reaction of chlorine nitrate with either water or hydrogen chloride is introduced into these models, then substantial depletions of ozone are calculated for the south polar region. The chemical observations related to Antarctic ozone depletion will be extensively discussed by other members of today's panel, and so will only be briefly summarized here.

The air which is over Antarctica at the beginning of winter is still there at the end of winter, and its stratosphere has become exceptionally cold during this long period of darkness. Because of this intense cold, particles (the PSCs, or polar stratospheric clouds) appear whose chemical composition is not fully established but which very probably have a lot of water ice connected with them. Furthermore, the Antarctic stratospheric air has probably spent considerable time at higher altitudes during the course of its transport from the equatorial regions where air parcels enter the stratosphere, and has become substantially depleted in nitrous oxide, N_2O, and very likely in methane as well. The nitrogen oxides normally present in daylight stratospheric air react to form the dimeric N_2O_5 in the darkness, and are then converted to nitric acid on the surfaces of the PSCs. At the same time, hydrogen chloride also sticks to the surface of the PSCs, and chlorine nitrate can then react either with water or with hydrogen chloride when it strikes the PSC surface. In this manner, heterogeneous reactions on the surface of the PSCs can prime the chemical composition of the Antarctic stratosphere for the arrival of the first sunlight of the Antarctic spring. When the sunlight does arrive, the chain removal of ozone can be expected to show a correlation with low temperature regions and the PSC clouds. These processes have presumably been taking place in this manner for decades or centuries with natural NO_x and with the small amount of chlorine from natural compounds such as methyl chloride. The largest factor for change in the situation in recent years is the massive build-up of organochlorine compounds in the atmosphere--from about 1.0 parts per billion in the troposphere in 1970 to more than 3.5 parts per billion in 1987.

When the sun appears anew on the horizon at the beginning of spring, atomic chlorine is released from the molecules Cl_2 and HOCl and immediately reacts with ozone to form the radical chlorine oxide, ClO. Three different second steps have been suggested for the radical ClO, and all probably take place to some extent: (1) reaction of ClO with the radical HO_2 [Solomon, Garcia, Rowland & Wuebbles, Nature, 1986]; (2) reaction of ClO with another ClO radical [Molina & Molina, J. Phys. Chem., 1987]; and reaction of ClO with the radical BrO [McElroy et al., Nature, 1986]. In each case, a sequence of reactions takes place which releases further atomic chlorine to repeat the cycle. Both the (ClO plus ClO) and (ClO plus BrO) reaction paths have alternate routes which result about half of the time in the formation of another chlorinated radical, chlorine dioxide, OClO, not previously observed in the atmosphere. These chain reaction routes can involve an appreciable fraction of the stratospheric chlorine present over Antarctica, and can run almost unhindered for a month or more because the usual chain-stoppers are for the most part inactive: the reaction of ClO with NO_2 is suppressed because most of the NO_2 has been sequestered as nitric acid; and the reaction of Cl with CH_4 is ineffective because its concentration is very low in this well-aged stratospheric air, and the reaction is slowed further by the very cold temperatures involved.

The various ClO chain reactions can then effectively remove ozone until the PSCs disappear and the chain-stopping NO_2 and CH_4 reappear, events which occur when the sun rises higher above the horizon, introducing additional heat to disperse the PSCs, causing the decomposition of nitric acid to release NO_2, and then breaking up the tight Antarctic polar vortex with air from other latitudes. The quantitative details of such reactions are not yet established--for example, what is the relative importance of the chain reactions of ClO with HO_2, ClO and BrO? What are the efficiencies of the chemical reactions on the surfaces of ice-like polar stratospheric clouds? [The unpublished laboratory studies of Drs. Mario Molina and Luisa Molina of the Jet Propulsion Laboratory have demonstrated that hydrogen chloride molecules stick on the surface of ice on almost every collision, making plausible the hypothesis that hydrogen chloride reactions can occur on the PSC surfaces.]

One of the major questions now confronting the atmospheric science community is the extent to which the observation of massive ozone depletion over Antarctica carries significance for the stratosphere in temperate and tropic regions. If heterogeneous reactions are occurring on polar stratospheric clouds, will similar reactions happen on particles in the stratosphere at other latitudes? Our inability to find any surface in the laboratory on which these chlorine nitrate reactions with water and with hydrogen chloride do not occur makes it quite plausible to us that such reactions can indeed take place on most particulate surfaces, and therefore in the stratosphere at other latitudes. However, because the chemical composition and physical structure of the stratospheric particles are not well-established either for the PSCs or for those found at other latitudes, quantitative transfer of any reaction rate information from one situation to the other is still highly speculative. In all likelihood, the appropriate quantitative modeling for such analogous heterogeneous reaction schemes will be narrowed down first through observations of actual chemical behavior in the temperate and tropical zone stratospheres.

We can turn finally to analyses of the actual long-term observations of the concentrations of stratospheric ozone. The technique of longest standing for such measurements utilizes an instrument called the Dobson spectrometer, developed in the 1920s and used at several locations during the 1930s. The physical basis for the Dobson measurement is the knowledge that ozone is capable of absorbing ultraviolet light, but that its absorption probability is quite variable with the wavelength involved. The technique as originated by Prof. Dobson involves pointing the instrument at the sun, and comparing the amounts of light received at two ultraviolet wavelengths, one of which is rather strongly affected by ozone in the atmosphere and one which is not. In this way, the recorded ratio of the two wavelengths provides a measure of the amount of ozone between the sun and the instrument. In practice, of course, many minor factors also enter, and a substantial number of auxiliary pieces of data, such as the temperature of the instrument, are needed as well. Over time, the procedure also became more elaborate with separate measurements for several pairs of wavelengths, each providing its own estimate of the amount of ozone in the atmosphere and therefore a check on the consistency of the entire set of observations. It should also be emphasized that the Dobson measurements were for many decades not taken with long-term changes in mind, but rather because of concerns with changes accompanying weather patterns over a few days or weeks, such as during the passage of a cold front.

The longest continual series of measurements with a Dobson instrument has been recorded in Arosa in the Swiss Alps, for which data are available on a nearly daily basis since August 1931. In addition, two Dobson instuments have been operated side by side there for about two decades to provide additional checks on the consistency of the recorded ozone concentrations. Many new Dobson stations were put into service at the beginning of the International Geophysical Year in 1957, including the Antarctic stations operated by the British Antarctic Survey at Halley Bay and Argentine Islands, which furnished the data for their first publication in 1985 about the very large losses of ozone incurred in the Antarctic spring. Additional stations also went into service during the 1960s, and there have been both additions and withdrawals of stations from service during the intervening 25 years. The data from Arosa demonstrate that: total ozone readings can vary substantially from one day to the next; a pronounced seasonal effect is observed with maximum readings in February and March about 25% higher than found in September and October; and the annual average ozone concentration also exhibits substantial variation from year to year.

The accumulated data from Arosa and from the other Dobson stations have been examined by statistical techniques by several research groups over the past decade in an effort to understand global ozone trends. Two major problems exist for these ground-based measurements of ozone over extended periods of time which affect such statistical analyses. The first is geographical because the Dobson stations are not distributed uniformly over the globe, but are instead concentrated in the north temperate zone in the United States, Canada, western Europe and Japan. In comparison, the coverage of the tropics and of the southern hemisphere by Dobson stations is sparse. This uneven distribution forces the choice of either seeking a global average for total ozone, in which the numerous north temperate zone stations play a relatively lesser role; or merely attempting a zonal average for that region in which a sufficiently large number of stations exists to permit cross-checking and calibration of one station against another.

The second problem with the Dobson stations is more troubling in attempts to determine whether the average amounts of ozone overhead might have changed over a period of 20 to 50 years: Has the Dobson spectrometer retained the same calibrated characteristics over the whole period of time? Have the operating personnel been consistent and careful over the entire period? The actual fact is that for a considerable number of Dobson stations, the data recorded in the World Ozone Data Center in Toronto have not been presented with sufficient care for them to be useful for the evaluation of long term trends in the data. Periodic recalibration of the Dobson spectrometers has frequently demonstrated substantial drift in the sensitivity of a particular instrument, but the data recorded immediately previous to the recalibration have usually not been corrected, or if they have been, the recalculated results have not been reported to the international data center. One of the 1987 NASA efforts now in progress, and with which I am closely involved, has been an attempt to evaluate the quality of the accumulated Dobson data, and to make as much of it as possible sufficiently checked, corrected and recalibrated to be useful for sophisticated statistical analysis.

In this recalibration and testing of world ozone data, the satellite measurements and the Dobson ground-based data play important complementary roles. The TOMS instrument on Nimbus 7 provides regular ozone measurements above every Dobson station, and intercomparisons can be made of the reported values by each technique. If, for example, most of the ground stations give ozone values in good agreement with the satellite or with a consistent small offset, but several of the ground stations show wide deviations, the results of the latter can be considered to be suspect. If a ground station is consistently or frequently in disagreement with the data from the satellite, then a detailed re-examination of the ground station measurement procedures is probably in order. In such cases examined to date, the satellite-Dobson intercomparison has sometimes brought to light Dobson recalibrations not properly recorded, or not properly applied to earlier data affected by the recalibration, and has triggered substantial improvements in the ground station data set. In other instances, the satellite-Dobson intercomparison has shown that the ground station is simply much too erratic for any recovery of good data, and can lead to a recommendation that the data reported from that station should be disregarded. It should be remembered that the Dobson measurements are frequently performed by a technician with many other daily responsibilities, a person often working from a manual and without a detailed knowledge of the physics of the procedure. Moreover, the resulting ozone data were often of only secondary interest to the station chief, so that a postulate of occasional routine error is not unreasonable.

The intercomparison procedure also works successfully in the other direction by validating the satellite data. The satellite instruments are exposed during operation to the full intensity of the sun, unshielded by any atmosphere, and consequently show obvious signs of progressive solar damage over the operating period of more than eight years. A procedure for repeated recalibration of the satellite instrument is available, but further consistency checks on any instrument that has been in space for almost nine years are clearly useful. In this situation, comparison of the satellite versus Dobson readings for the "validated" Dobson stations can furnish an important check on the calibration of the satellite instrument to determine whether any drift exists in its readings from year to year. The Nimbus-7 overpasses of all Dobson stations apper to show only a very small drift, averaging 0.4% per year, in these intercomparisons covering the 8-year period. These overpasses still include both well-run and not so well-run Dobson stations, and will be re-checked after the ground stations have been winnowed down by eliminating those whose data prove the most doubtful. These validation procedures for both the Dobson stations and the satellites are being carried on simultaneously now in the NASA study, with completion of much of the work scheduled for late 1987.

In the meantime, our research group at the University of California Irvine has examined the data from some of the Dobson stations which are believed to be among those with the better measurements. Our examination of the Arosa data [Harris and Rowland, Amer. Geophys. Union, San Francisco, Dec. 1986] has brought out some characteristics not previously reported. Perhaps the most significant was the observation that the Arosa ozone data show seasonal differences in the trends over time. Our evaluation of the Arosa data from August 1931 through July 1986 have indicated a decrease during the winter months of as much as 6% in the total ozone in the mid-1980s versus the 1931-1970 period, and decreases of no more than 1% in the late summer months. The previous statistical analyses have been conducted on the assumption that any ozone depletion caused by increasing concentrations of organo- chlorine compounds in the atmosphere would be consistent throughout the year, but the actual data from Arosa indicate that this assumption is not correct, at least for that station. From our analysis, we have calculated an average decrease of about 3% in total ozone over Arosa in the period since about 1970, but with this loss unevenly distributed over the year, larger toward winter and smaller toward summer.

The data for Arosa are really only applicable for that particular location, and the question immediately can be raised as to whether this location carries any implications for the rest of the world. Several other Dobson stations at similar latitudes have continual runs of data for 20 years or more, and we have examined these for comparison with the Arosa conclusions. The U.S. Dobson stations at Caribou, Maine [47°N, 68°W], and Bismarck, North Dakota [47°N, 101°W], and the Canadian station at Goose Bay, Labrador [53°N, 60°W], are all at similar latitudes to Arosa [47°N, 10°E], and each displays a similar pattern to that observed over Switzerland, with a decrease as large as 5-7% in the winter months and very little in the late summer. On the other hand, the Japanese station at Sapporo [43°N, 141°E], on the northern island of Hokkaido does not appear to have any large decreases in total ozone at any month or season. At the same time, the meteorological circumstances of Sapporo appear to be rather different from those applicable to Arosa, Goose Bay, Bismarck and Caribou. Our present conclusion is that the Dobson network is indicating decreases of ozone amounting to about 3% averaged over the year at several relatively high latitude stations in the northern hemisphere, although not at all, being perhaps dependent on the frequency with which Arctic air sweeps over them. It is perhaps not coincidental that the latest 2-D models predict considerably larger decreases in total ozone 40º-60º latitude belt than near the equator. In any event, the existing analyses of global ozone data both by satellite and from the Dobson ground-based network suggest that the recently observed decreases in ozone concentrations have not been confined to the polar regions.

STATEMENT OF

Dr. Robert T. Watson

Office of Space Science and Applications

before the

Subcommittee on Environmental Pollution

Committee on the Environment and Public Works

United States Senate

Mr. Chairman and Members of the Subcommittee:

I am pleased to be here today to discuss four separate issues in my testimony: (A) the conclusions reached at an UNEP sponsored Ad-Hoc Scientific Meeting to Compare Model Generated Assessments of the Ozone Layer Change for Various Strategies for CFC Control, held in Wurzburg, Federal Republic of Germany, April 9-10, 1987; (B) the conclusions of the Scientific Working Group at the UNEP sponsored Ad-Hoc Group of Legal and Technical Experts for the Preparation of a Protocol on Chlorofluorocarbons to the Vienna Convention for the Protection of the Ozone Layer, held in Geneva, Switzerland, April 27-30, 1987; (C) the process by which NASA, in conjunction with other National and International scientific agencies, is performing a detailed reexamination of all ground-based and satellite observations of the total column content and vertical distribution of ozone in order to establish the accuracy and reliability of these data sets and to assess the evidence of recent trends in the abundance and distribution of ozone on a global scale; (D) a description of the multiagency cosponsored Antarctic Ozone Hole research planned for August to October of this year.

A. Conclusions of the Wurzburg Meeting:

This meeting was sponsored by UNEP and attended by a small group of theoretical modelers from the United States of America, the United Kingdom, Belgium, and Norway. The group met to intercompare the results of their predicted ozone changes as a function of time for a range of possible control options (emission scenarios) for different chlorofluorocarbons using one and two-dimensional model calculations. The control options were developed by UNEP in consultation with the Vienna Group Chairman Dr. Lang. These control options spanned a range of assumptions concerning; (a) the list of potential ozone-depleting substances to be included in the protocol; (b) the extent and rate of future reductions beyond a freeze; (c) compliance, i.e. the fraction of countries adopting the protocol; and (d) the rate of growth of CFC use in the developing countries. A copy of the "Wurzburg" report is submitted for the record with my testimony.

The main conclusions of the meeting were, in my own words:

(1) All models, including the fully parameterized model developed at the Lawrence Livermore National Laboratory and used by the U.S. EPA, calculated, within acceptable limits of agreement (approximately 50 percent), similar ozone depletions for given CFC control strategies.

(2) A true global freeze of the emissions of all chlorine and bromine containing compounds at or below projectd 1990 levels is calculated to result in global column ozone depletions of less than 2 percent by the year 2050. However, even when column ozone depletions are calculated to be small, or do not occur, redistribution of ozone in the vertical column is still calculated to occur. In addition, two-dimensional models indicate that column ozone depletion greater than the global average will occur at high latitudes and that smaller depletions will occur near the equator.

(3) Ozone depletion was calculated to occur for all regulatory scenarios examined. This included the case of an immediate freeze in the emissions of all fully and partially halogenated substances, including the Halons (1211 and 1301), followed by a 50 percent reduction in emissions within 6 years, with 100 percent compliance in the developed world. The reason for the calculated ozone reduction in this case was the growth in CFC use projected for the developing countries by the U.S. EPA.

(4) Regulatory measures limited to CFC's 11 and 12 only would still result in significant growth in the halogen loading of the stratosphere, and hence in calculated ozone depletion, given the projected growth rates of CFC 113 and Halons 1211 and 1301 by the U.S. EPA.

(5) Broad coverage of chemicals and international participation are essential to limit the growth in the halogen loading of the stratosphere and hence calculated ozone depletion. Growth in non-complying developing countries must be limited.

B. Conclusions of Scientific Working Group in Geneva:

The scientific working group which I chaired was primarily charged with providing advice on the scope, and priority, of chemicals to be included in the protocol; recommendations of values for the Ozone Depleting Potential (ODP) for a range of halogenated chemicals; and a review of the Wurzurg report. A copy of the scientific working group report is submitted for the record with my testimony.

The main conclusions of the scientific working group were, in my own words;

(1) Both the total column content and the vertical, latitudinal, and seasonal distribution of atmospheric ozone respond to the total chlorine and total bromine loading of the stratosphere.

(2) Factors governing the relative efficiency of the chemicals to

deplete ozone are recognized to be:

(a) Rate of release of the chemical into the atmosphere;
(b) Rate of removal of the compound in the troposphere and its persistence in the stratosphere;
(c) Efficiency of the chemical in destroying ozone in the stratosphere.

Combining factors (b) and (c) results in a quantity known as the Ozone Depleting Potential (ODP).

(3) It is recognized that at present CFC's 11 and 12 combined are the largest contributors to the predicted depletion of ozone (approximately 70 percent), and at its current production, CFC 113 is predicted to contribute about 12 percent to the ozone depletion. However, it is clear that a protocol which allowed substitution of CFC's 11 and 12 by other fully halogenated CFC's, such as CFC's 114 and 115, would not protect ozone due to the large ODP values and long lifetimes of these substitute chemicals. Therefore, from a scientific perspective, the protocol should consider all of the fully halogenated chemicals, including the Halons, which are very long-lived as a group for the purposes of regulation.

(4) Chemicals that have low ODP values such as CFC's 22, 123, and 132b have significant value as substitutes.

(5) The scientific working group underscored not only the importance of considering predicted global column ozone changes in selecting a control strategy, but also the predicted changes in the vertical and latitudinal distribution of ozone.

(6) It is recognized that an additional atmospheric property of the CFC's is their potential to contribute to the greenhouse warming. Consequently, this property needs to be quantified for all CFC's for judging their acceptability as substitutes.

(7) There was a strong endorsement for the need for:

(a) continued scientific research;
(b) long-term measurements, including the implementation of the network for ground-based instrumented stations to detect changes in the chemical composition and the physical structure of the stratosphere; and
(c) major scientific assessments every 4 years, and on an emergency basis as needed.

(8) In general the conclusions of the Wurzberg report were endorsed by the Scientific Working Group. It was also noted that the predicted levels of ozone change are sensitive to the scenario assumptions adopted for carbon dioxide, methane, and nitrous oxide. Representatives of the European Industry questioned both the values of the projected growth rates and fraction of current CFC production consumed in the developing countries as provided

by the U.S. EPA for the model calculations.

(9) There are many uncertainties regarding the ability of models to accurately represent the present and future atmosphere. Unexpected and unexplained changes to the atmosphere may occur. Provision should be made within the proposed protocol for prompt response to significant ozone changes or to significant changes in scientific knowledge.

C. NASA Review Process of Satellite and Ground-Based Ozone Data:

One of the key questions that is always asked in conjunction with the CFC-ozone issue is whether changes in the abundance and distribution of ozone have been observed, and whether these changes are consistent with the CFC-ozone depletion theory. Satellite and ground-based observations of both the total column content and vertical distribution of ozone can be used to detect changes. The NASA report to the EPA and Congress in 1986, which was based on the large international scientific assessment cosponsored by NASA, NOAA, FAA, WMO, UNEP, the Commission of the European Communities (CEC) and the Bundesministerium Fur Forschung und Technologie (BMFT) entitled "Atmospheric Ozone 1985: Assessment of Our Understanding of the Processes Controlling its Present Distribution and Change," stated:

> "The search for global ozone trends involves looking for small secular changes amidst large natural variations that occur on many time scales. Statistical methods must be used on the data which are available from relatively few stations. In general, analyses for the trends in the total column ozone show no statistically significant trend since 1970 in agreement with model predictions for the same period when the change in all of the trace gases are taken into account. Because abnormally low ozone values were observed in 1983, one analysis ending in that year showed a downward trend. Values of total ozone have risen again in 1984 such that the trend apparently disappears. Total ozone measurements in 1985 and 1986 should make it apparent whether a trend has begun or whether 1983 was simply an anomalous year possibly due to the El Chichon volcanic eruption and/or the large El Nino that took place during this period. Trend estimates have also been made for the altitude profile of ozone from the network of stations observing using the Umkehr method. Fewer Umkehr stations exist than those that observe total ozone. Umkehr measurements are made more difficult because of the need to eliminate aerosol effects, such as those from volcanic eruptions, on the derived ozone amounts. After adjusting the ozone measurements for the aerosol contribution, an estimate of the ozone trend in the middle and upper stratosphere gives a 2 to 3 percent decrease for the period 1970 to 1980. This is consistent with the predictions of photochemical models which give similar changes in ozone at this level."

Since this report was published, additional ground-based and satellite ozone observations have been reported. In particular, a preliminary analysis on Nimbus 7 satellite Solar Backscatter Ulraviolet (SBUV) data indicates that both the total column and vertical distribution of ozone have decreased significantly, of the order of several percent since 1979. Further analysis of the data indicates that most of the change has occurred since 1981. Examination of the ground-based Dobson and Umkehr data also seems to indicate that ozone has decreased globally since 1979. However, it should be noted that the total global ozone column was high in 1979 compared to the historical average. The amount of ozone as measured by the Dobson network in 1985 was within 1-2 percent of the amount present during the early 1960's (see figure 1).

NASA and the rest of the scientific community believe that it imperative that all ground-based and satellite ozone data be reanalyzed and interpreted as soon as possible. It is crucial to evaluate whether the data has been analyzed correctly, and if so, whether the decrease since 1979 is due to natural causes such as a decrease in solar radiation, the 1982 eruption of El Chichon, or the 1982 El Nino event, or whether it is due to human activities such as the use of chlorofluorocarbons. Therefore, during the fall of 1986 NASA in conjunction with the Federal Aviation Administration (FAA), the National Oceanic and Atmospheric Administration (NOAA), the World Meteorological Organization (WMO), and the United Nations Environmental Program (UNEP) launched a major review of all ozone data. An ozone trends panel composed of eminent scientists from federal agencies, research institutions, private industry, and universities was selected in early November and first met in mid-December 1986. Table 1 lists the Panel and their Organization affiliations. The report will focus on trends in ozone, both total column and vertical profile. Full understanding will require parallel consideration of tends in other important parameters: temperature, solar flux, nitrogen oxides, chlorine oxides, etc. Table 2 lists the subgroups formed to critically evaluate specific aspects of the study, along with the names of the subgroup chairmen and committee members. Four of these subgroups were established in December 1986 and have made significant progress to date. These subgroups are studying:

(a) Calibration Procedures and Instrument Performance;
(b) Information Content of Algorithms;
(c) Satellite-Satellite Data Intercomparisons;
(d) Satellite-Ground-Based Data Intercomparisons.

An additional seven subgroups were established in March 1987 and have only just started their work:

(e) Comparison of Observed and Theoretically Predicted Trends;
(f) Trends of Other Chemical Constituents in the Stratosphere;
(g) Statistical Procedures used to Analyze Trend Data;
(h) Trends in Source Gases, e.g. CO2, CH4, N2O, and CFC's;
(i) Aerosol Abundances and Distributions;
(j) Trends in Stratospheric Temperatures;
(k) Observations and Theories Related to the Antarctic Ozone Hole.

Twenty meeting have already occurred or been scheduled for the Ozone Trends Panel or subgroups and more will be set up in the coming months. A meeting schedule is shown in Table 3. We anticipate that at the mid-June meeting, the four original subgroups will prepare an interim report, with a final report by the end of the year. Following precedent, the report will be peer-reviewed. Each chapter of the final report will be reviewed by other members of the panel as well as external reviewers who will critique the entire report.

D. 1987 Antarctic Ozone Campaign:

The sudden large and unexpected decrease in springtime ozone over Antarctica during the last decade is one of the most important and challenging issues currently facing the scientific community in all of Earth sciences. It is still not evident whether the behavior in Antarctic ozone is due to a natural phenomena or due to human activities such as the release of CFC's into the Earth's atmosphere, and it is not clear whether it is an early warning of future changes in global ozone or whether it will always remain confined to the Antarctic region due to the special geophysical conditions that exist there. Given the importance of understanding the observations of the ozone decrease over Antarctica in a timely manner, NASA, NOAA, National Science Foundation (NSF), and the Chemical Manufacturers Association (CMA) mounted a ground-based campaign at McMurdo Bay in 1986. The results of this campaign will be reviewed later in this session before this subcommitte by the scientists who went to McMurdo. However, while this campaign was a major success with excellent data on the chemical composition of the springtime Antarctic atmosphere, it is clear that additional scientific data is required for further refinement of our understanding of the processes controlling ozone in and around Antarctica.

Therefore NASA, NOAA, NSF, and the CMA are mounting a major campaign using ground-based, aircraft, and satellite instrumentation during the Antarctic springtime, from mid-August onwards, in 1987. This consists of two components: (a) the 1987 ground-based campaign, coordinated by NSF at McMurdo which will be somewhat expanded in scope compared to the 1986 NOZE I campaign; and (b) A 1987 aircraft campaign, organized and managed by NASA on behalf of the four agencies, using the NASA ER-2 and DC-8 aircraft as platforms for instruments operated by scientists from NASA Centers, the NOAA Aeronomy Laboratory, the National Center for Atmospheric Research, universties and private industry. This campaign will also utilize real-time satellite data. This aircraft campaign has been afforded the highest possible priority within the Earth Science and Applications Division at NASA Headquarters and at the NASA Ames Research Center in California where the aircraft are maintained and operated.

Dr. Tuck from the NOAA Aeronomy Laboratory who has been selected as the project scientist for the aircraft component of this campaign, will describe in detail before this subcommittee in the the panel on Antarctic ozone the scientific goals, strategy, philosophy, and scientific progress expected from this campaign. Table 4 briefly outlines the scientific payloads selected for both the DC-8 and ER-2 aircraft in order to support or refute the proposed solar, dynamical, or CFC theories. The scientific payload has also been scoped in order to obtain a broad base of scientific data in case all currently proposed mechanisms are incorrect. The campaign, which will involve over 100 scientists, engineers and pilots will be based in Punta Arenas, Chile, and is planned to begin mid-August and continue until the beginning of October.

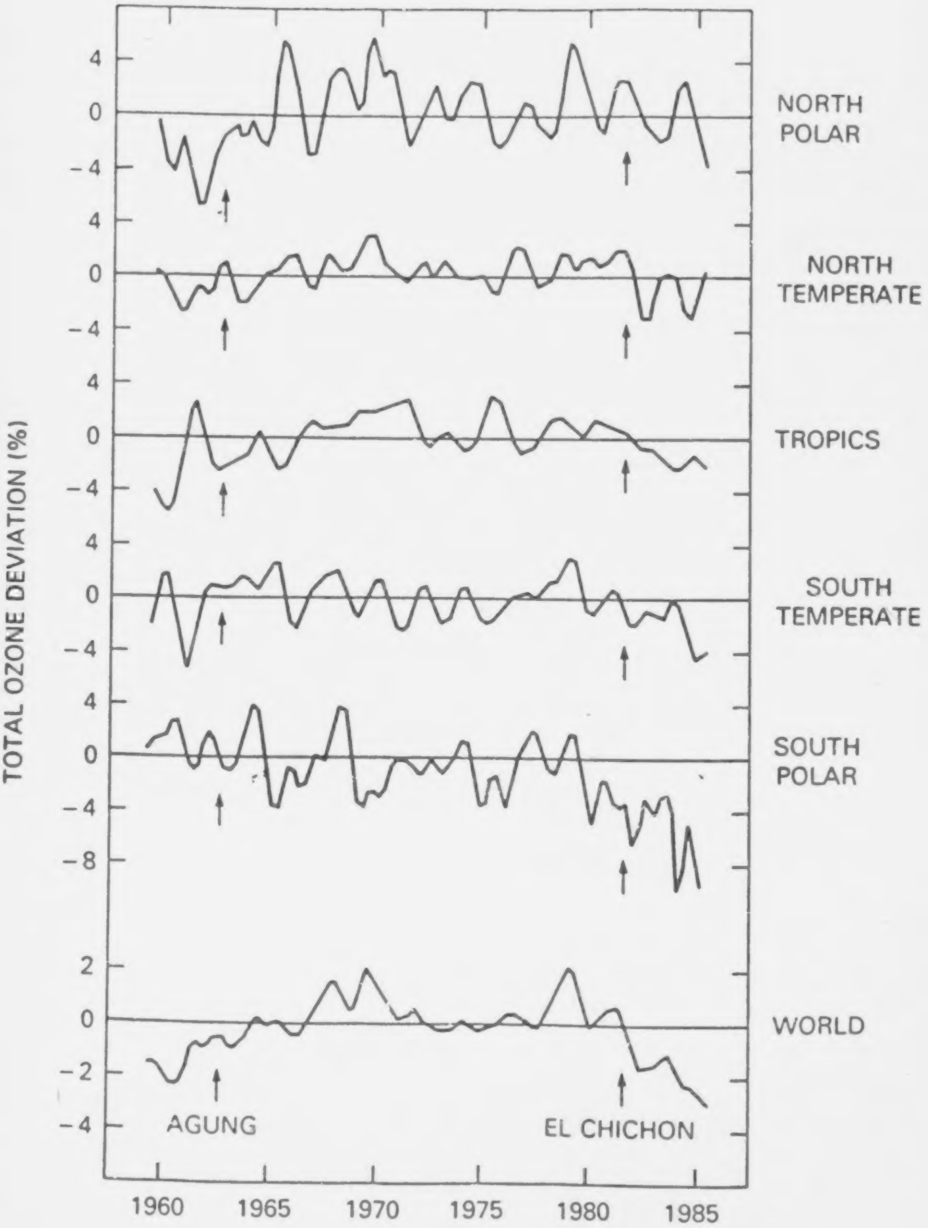
TOTAL OZONE DEVIATION (%)
4
0
-4
NORTH POLAR
NORTH TEMPERATE
TROPICS
SOUTH TEMPERATE
SOUTH POLAR
-8
2
-2
WORLD
AGUNG
EL CHICHON
1960
1965
1970
1975
1980
1985

Figure 1

Table 1

Ozone Trends Panel

MEMBER & AFFILIATION	CITY
Albritton, D. NOAA Aeronomy Laboratory	Boulder, CO
Bloomfield, P. North Carolina State University	Raleigh, NC
Bujkov, R. Atmospheric Environment Service	Downsview, Ontario, Canada
Curran, R. NASA Hqts.	Washington, DC
Ehhalt, D. GMBH Institute fur Chemie	Julich, West Germany
Gille, J. National Center for Atmospheric Research	Boulder, CO
Hartmann, D. University of Washington	Seattle, WA
Hudson, R. NASA Goddard Space Flight Center	Greenbelt, MD
Isaksen, I.S.A. University of Oslo	Oslo, Norway
Johnston, H. University of California	Berkeley, CA
Mahlman, J. NOAA Geophysical Fluid Dynamics Laboratory	Princeton, NJ
Margitan, J. NASA/Jet Propulsion Laboratory	Washington, DC
McCormick, P. NASA Langley Research Center	Hampton, VA
McFarland, M. The DuPont Company	Wilmington, DE
Ormond, F., Executive Secretariat ORI, Inc.	Washington, DC
Rodgers, C. Oxford University/ NCAR	Boulder, CO & Oxford, UK

Rowland, F. S. University of California	Irvine, CA
Stolarski, R., **Vice Chairman** NASA/Goddard Space Flight Center	Greenbelt, MD
Turco, R. R&D Associates	Marina Del Rey, CA
Watson, R. T., **Chairman** NASA Hqts.	Washington, DC

Table 2

CALIBRATIONS WG
J. Gille, Chairman
P. Feldman
R. Hudson
J. Lean
R. Madden
L. McMaster
G. Mount
G. Rottman
P.C. Simon

ALGORITHMS WG
C. Rodgers, Chairman
P.K. Bhartia
W.P. Chu
R. Curran
J. DeLuisi
J. Gille
R. Hudson
C. Mateer
D. Rusch
R.J. Thomas
R. Turco
W. Wiscombe

SATELLITE/SATELLITE INTERCOMPARISONS WG
H. Johnston, Chairman
A. Aikin
R. Barnes
S. Chandra
D. Cunnold
J. DeLuisi
R. Hudson
J. Lawrence
M.P. McCormick
L. McMaster
E. Remsberg
D. Rusch
C. Trepte
R. Veiga
P. Wang
C. Wellenmeyer

SATELLITE//GROUND INTERCOMPARISONS WG
F.S. Rowland, Chairman
P. Bloomfield
R. Bojkov
N. Harris
M. McFarland
R. McPeters

R. Stolarski

NEWLY FORMED WGS
(still organizing membership)

COMPARISON OF THEORY AND OBSERVATIONS WG
I. Isaksen, Chairman
M. Ko
J. Pyle
H. Rodhe
R. Stolarski
R. Turco
D. Wuebbles

OTHER TRENDS IN STRATOSPHERE WG
R. Stolarski, Chairman
M. Coffey
M.P. McCormick

STATISTICAL APPROACH WG
P. Bloomfield, Chairman
R. Stolarski

SOURCE GASES WG
D. Ehhalt, Chairman
D. Albritton
S. Rowland

AEROSOLS WG
R. Turco, Co-Chairman
M.P. McCormick, Co-Chairman
R.T. Clancy
R. Curran
J. DeLuisi
P. Hamill
G. Kent
J. Rosen
O.B. Toon

ANTARCTIC OZONE WG
R.T. Watson & D. Hartmann, Co-Chairmen

TEMPERATURE WG
Chairman - TBA

Table 3
OZONE TRENDS PANEL AND WORKING GROUP MEETINGS

Date	Meeting	Chairman
12/15-16/86	OZONE TRENDS PANEL NASA Goddard, Greenbelt MD	R.T. Watson NASA Hqts.
1/21/87	Data Intercomparisons Satellite/ Satellite WG - Preliminary mtg. NASA Langley, Hampton, VA	H. Johnston U. CA - Berkeley
2/12-13	Algorithms WG Boulder, CO	C. Rodgers Clarendon Labs Oxford, UK (at NCAR now)
2/19-20	Calibrations Instrument Performance WG - NASA Goddard, Greenbelt MD	J. Gille NCAR
3/9-10	Data Intercomparisons S/S NASA Langley, Hampton, VA	H. Johnston U. CA - Berkeley
3/12-13	Dobson/Umkehr Intercomparisons WG Newport Beach, CA	F.S. Rowland U. CA - Irvine
3/19-20	Calibrations Instrument Perf. Boulder, CO	J. Gille NCAR
3/23-24	OZONE TRENDS PANEL Boulder, CO	R.T. Watson NASA Hqts
4/14-15	Algorithms WG LASP, Boulder, CO	C. Rodgers at NCAR
5/4-5	Other Trends in Stratosphere WG Preliminary meeting NASA Langley, Hampton, VA	R. Stolarski NASA Goddard
5/12-13	Dobson/Umkehr S/Ground Inter. Atmospheric Environment Service Downsview, Ontario, Canada	F.S. Rowland U. CA - Irvine
5/17	Satellite/Satellite WG NASA Goddard, Greenbelt, MD	H.S. Johnston U. CA - Berkeley
5/21-22	Theory & Observations WG Oslo, Norway	I. Isaksen U. Oslo
5/21-22	Calibrations Instrument Perf. Johns Hopkins University Baltimore, MD	J. Gille NCAR
May	Source Gases WG	D. Ehhalt

	in planning	GMBH, W. Germany
May - July	Aerosols WG in planning	R. Turco R&D Associates Marina del Ray, CA
6/18-19	OZONE TRENDS PANEL NASA Goddard, Greenbelt, MD	R.T. Watson NASA Hqts.
6/22-26	Antarctic Ozone Symposium/WS NASA Ames (proposed)	R.T. Watson & D. Hartmann, U. WA - Seattle
June - July	Statistical Approaches WG Planning stage	P. Bloomfield NC State - Raleigh
________	Temperature WG	Chairman - TBA
Sept/Oct	OZONE TRENDS PANEL Editorial Mtg Planning stage	R.T. Watson

Table 4

Antarctic Ozone Project

Aircraft Payloads

PI	Inst.	Instr./Meas.
ER-2		
Chan	ARC	MMS
Starr	ARC	Ozone
Proffitt	NOAA	Ozone
Anderson	Harvard	ClO,BrO
Kelly	NOAA	H2O
Fahey	NOAA	NOy
Gary	JPL	MTP
Loewenstein	ARC	N2O
Vedder/Heidt	ARC/NCAR	Whole Air Sampler
Ferry/Knollen.	ARC/PMS Inc.	Aerosol
Wilson	U Denver	Cond. Nuc
Gandrud	NCAR	Filters
Oberbeck	ARC	Particles
DC-8		
Browell	LaRC	Lidar -O3/aerosols
Gregory	LaRC	In situ O3
Kelly	NOAA	Water
Wahner	NOAA	OClO, BrO
Mankin/Coffey	NCAR	FTIR
Farmer	JPL	FTIR
Heidt/Vedder	ARC/NCAR	Whole air sampler

Ground/Satellite Data

Krueger	GSFC	TOMS
Jones	Brit. Met. Office	Forecast/Trajectories

Theory/Analysis Group

Tuck/Jones	NOAA/BMO	Trajectories
Toon	ARC	Aerosols
Sze	AER	Photochem.
-----	----	Dynamics

TESTIMONY OF

DR. SUSAN SOLOMON
RESEARCH CHEMIST
AERONOMY LABORATORY
ENVIRONMENTAL RESEARCH LABORATORIES
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

BEFORE THE

SUBCOMMITTEE ON ENVIRONMENTAL PROTECTION
AND
SUBCOMMITTEE ON HAZARDOUS WASTES AND TOXIC SUBSTANCES
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
UNITED STATES SENATE

MAY 12, 1987

Mr. Chairmen and Members of the Subcommittees:

I appreciate the opportunity to discuss research on the Antarctic ozone anomaly before you today.

The Antarctic ozone anomaly was first detected by the British Antarctic Survey. These scientists had been measuring total ozone in the Antarctic since 1957. Remarkably, their thirty-year record of ozone measurements in the remote Antarctic is among the longest anywhere in the world. For the first twenty years or so, the ozone layer above Antarctica was relatively constant, exhibiting only year-to-year fluctuations of the monthly averaged values of about 10%, which is comparable to variability observed in other parts of the world. These fluctuations are undoubtedly caused largely by annual variations in atmospheric dynamics. In the past ten years, on the other hand, the ozone observed in Antarctic spring has systematically decreased, so that the ozone layer over the Antarctic today is only about half as thick as it was in the late 1960's and early 1970's. The change occurs primarily in the spring season. This is by far the largest perturbation to the ozone layer ever documented.

It is well known that atmospheric scientists have predicted that increasing levels of chloroflurocarbons should be expected to produce changes in the Earth's ozone layer. These changes are expected to be global in their extent. Although chloroflurocarbons are produced largely at mid-latitudes in the Northern Hemisphere, their abundances become mixed throughout the world much more rapidly than they are destroyed. Therefore, they are a global rather than regional pollution problem. Such ozone changes are, however, anticipated to be both much smaller and much later than those being observed in the Antarctic today. Theoretical model studies carried out prior to the discovery of the Antarctic ozone depletion suggested ozone changes on the order of five percent, occurring about fifty to one hundred years from now. I will refer to such model calculations as "standard theory".

The remarkable and unexpected change in the ozone layer observed above the Antarctic today has come to be known as the Antarctic ozone "hole". A number of theories, both chemical and dynamical, have been advanced to explain the ozone hole through chemical processes. An inter-agency National Ozone Expedition funded by the National Science Foundation, the National

Aeronautics and Space Administration, the National Oceanic and Atmospheric Administration, and the Chemical Manufacturers Association, went to Antarctica during August to November, 1986, to examine the ozone hole firsthand and to try to measure a broad range of chemical compounds. I will briefly describe the chemical theories, and I will summarize the observations made during the National Ozone Expedition which bear upon those theories.

The interaction of the Sun with the Earth's upper atmosphere leads to the production of oxides of nitrogen at altitudes about 100 kilometers above the surface. These molecules play an important role in the photochemistry of ozone in the stratosphere. One theory suggests that enhanced levels of nitrogen oxides associated with high solar activity levels near 1980 might be transported down to the stratosphere, where they could be responsible for the recent ozone trend. This theory therefore implies that levels of nitrogen oxides should be high in the region where the ozone levels are low.

In a second theory, the scientists from the British Antarctic Survey suggested that the cause of the ozone hole might be chloroflurocarbons, and that the unique conditions of the Antarctic might make this region more susceptible to ozone destruction by chlorine than other parts of the world. Specifically, the Antarctic is by far the coldest place on Earth, both on the ground and at the altitudes near 15 to 20 kilometers where the Antarctic ozone layer is found. They suggested that these cold temperatures might lead to unusual chemical processes. Other scientists have since made a number of important additions or modifications to these ideas. Specifically, it has been pointed out that the interactive chemistry of chlorine and bromine might be particularly important in the Antarctic. A synergestic effect between these two species can make them much more effective at destroying ozone than either in isolation. Also the chemistry of a dimer of chlorine oxide has been shown to be potentially very important in destroying ozone in the Antarctic stratosphere. Further, it has been noted that polar stratospheric clouds might play an extremely important role in Antarctic photochemistry. The stratosphere is normally too warm for clouds of ice particles to form, but observations have shown that a unique feature of the Antarctic stratosphere is the widespread occurrence of polar stratospheric clouds during winter and early spring. Such clouds form only very rarely in the Arctic. A number of laboratory studies suggest that chemical processes which do not occur in the gas phase might proceed rapidly on such cloud surfaces. These reactions reduce the levels of nitrogen oxides and increase those of chlorine oxides, which can then go on to destroy ozone in this region. Thus the halocarbon theories require a behavior for nitrogen oxide that is essentially opposite to that of the solar activity theory.

The ozone hole is a strongly seasonal phenomenon. The National Ozone Expedition did a great deal to clarify our understanding of the vertical and temporal changes in ozone associated with the hole. We arrived in Antarctica in late August to find total ozone levels and profiles that I would describe as rather normal for that latitude and time of year. In the next several weeks, we witnessed about a 35% reduction of the ozone overhead. In addition to the strong evidence provided by the historical data extending back to the 1950's and 1960's showing a long-term change in Antarctic ozone, I emphasize that the behavior observed in a single spring season clearly reveals the growth of the hole. Similar trends have been established from studies with NASA satellites. It would be highly desirable to make future observations earlier (early August) to more fully study the seasonal cycle of the hole.

The levels of nitrogen dioxide and nitric oxide observed in the Antarctic during the National Ozone Expedition were extremely low. The measured abundances of nitrogen dioxide were only about one-third as large as Arctic observations or standard theoretical models. This shows that the chemistry of the Antarctic stratosphere is anomalous with respect to standard theory. The low abundances observed are consistent with the halocarbon models of the ozone hole involving the unique surface chemistry of polar stratospheric clouds, but do not prove that such models are correct. The fact that the ozone hole was associated with low rather than high levels of oxides of nitrogen is in conflict with predictions by the solar activity theory. Further, the vertical profile of the seasonal ozone change was maximum near 15 to 20 kilometers altitude, while the solar activity theory predicts larger changes at higher altitudes.

Observations of chlorine containing molecules are of prime importance in studying the possible role of halocarbon chemistry in the development of the ozone hole. Chlorine monoxide was measured during the National Ozone Expedition and found to be present at about one part per billion by volume level near 20 km. This is about a hundred times greater than standard model predictions, and is roughly consistent with some models of the ozone hole invoking halocarbon chemistry possibly associated with polar stratospheric clouds. Chlorine dioxide is a closely related molecule which is believed to reflect the chemistry of both chlorine and bromine. It was also found to be present in amounts some twenty to fifty times greater than standard theory, in good agreement with the chlorine monoxide measurements and with some halocarbon theories of the ozone hole. These observations clearly demonstrate that the chlorine chemistry of the Antarctic stratosphere is highly anomalous.

There are a number of important uncertainties involved in this anomalous chlorine chemistry and its possible relationship to the ozone hole. Foremost among these are uncertainties in the rates of critical kinetic processes. These must be better quantified by laboratory work. Further studies of the distribution and chemistry of polar stratospheric clouds are also vital. The chemical observations that I have discussed establish that the chemistry of the Antarctic stratosphere is anomalous but do not prove that these anomalies are sufficient to be the sole cause of the ozone hole. Better laboratory data and further Antarctic measurements are badly needed.

I anticipate that a great deal will be learned about the ozone hole this coming austral spring season. The second National Ozone Expedition will probably add a great deal to the knowledge gathered on the first expedition. In particular, concurrent measurements of polar stratospheric clouds will be important in understanding the role of cloud processes. I am hopeful that this year's experiment may begin somewhat earlier than the last expedition in order to study the full seasonal evolution of the ozone hole. The measurements made during the National Ozone Expedition are mostly ground-based experiments, which can provide only very limited information on the altitude distribution of most of the molecules I have mentioned. Local measurements directly inside the ozone hole to be performed by a planned series of aircraft experiments this austral spring will provide much better height information on the distributions of all of the molecules I have discussed, as well as many more which are of critical importance. The cloud distribution will be measured concurrently. This series of aircraft experiments will be key to future studies of the ozone hole.

In summary, the ozone layer above Antarctica has changed in ways that are not fully understood at present. The long-term trend that has happened over the past decade or more is also manifested in an abrupt and anomalous seasonal decline obtained in a single spring season. The results from the National Ozone Expedition, 1986, display strong evidence for anomalous photochemistry in the Antarctic stratosphere which may be related to the ozone changes.

Mr. Chairmen, this concludes my presentation. I want to thank you again for this opportunity, and I will be glad to answer any questions you and the Members of the Subcommittees may have.

Statement of
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Presented before
the Joint Subcommittees of
Hazardous Waste and Toxic Substances
and
Environmental Protection
of
the U.S. Senate Committee
of
Environment and Public Works
on
May 12, 1987 .

Mr. Chairman and Members of the Subcommittees.

During the past two years, many of us in the atmospheric sciences community have been asking ourselves: "Is it chemistry or is it dynamics?" We are referring, of course, to the unknown cause of the Antarctic ozone-hole phenomenon. The declining ozone content over Antarctica in recent years was first noted in the May 1985 issue of Nature by the scientists from the British Antarctic Survey. It took a few months before the phenomenon was confirmed by NASA scientists analyzing satellite data. Several groups then started to search for a cause.

Dr. Susan Solomon, who is testifying here today, was the first, along with her coworkers, to come up with a chemical theory relating the large ozone depletion to increased stratospheric chlorine content due to CFC (chlorofluorocarbon) emissions. Professor Michael McElroy of Harvard University and his coworkers suggested a different chemical scheme but again attributed the ozone depletion to CFC increases. My coworkers and I were the first to suggest a dynamical theory, relating the observed ozone change to changes in air circulation patterns when the sun returns to this part of the world each September. Air motion can decrease the total ozone concentration at a particular latitude if ozone-poor air in the lower atmosphere is brought up to the lower stratosphere (the 15 to 25 km region), displacing ozone-rich air to other latitudes. Dr. Linwood Callis and his coworkers later proposed that the ozone depletion in question should instead be attributed to enhanced levels of nitrogen oxides produced during a certain phase of the solar cycle. These theoretical papers have all been published in Nature during the last year. About forty more papers on the subject appeared in the November 1986 special issue of Geophysical Research Letters.

There has not been, however, enough time for the scientific community to come to a consensus as to whether the phenomenon is caused by increased CFC's or is just a manifestation of natural dynamical fluctuations in short and long time scales. There is not even a consensus on whether the declines in ozone since 1979 observed by satellite constitutes a long term trend, or is simply a coincidence of three large declines, one in 1980, another in 1983 and the last one in 1985. In the intervening years, El Chichon erupted in April 1982. Volcanic dust and aerosols appeared in great quantities in the Antarctic stratosphere during winter and spring of 1983. This, and a large El Nino event, were superimposed upon a CFC trend.

To complicate matters even more, observations showed that the ozone decline over Antarctica has not been monotonic —— a decrease in one year usually (but not always) has been followed by an increase in the year after. For example, 1984 has higher ozone amounts than 1983, and 1986 is higher than 1985. We are very interested in finding out what will happen to Antarctic ozone in the next two years; no one is yet confident enough to predict, based on past record, whether the downward trend observed until 1985 will resume or the recovery began in 1986 will continue. There is so much uncertainty about this part of our atmosphere that it will probably take a few more years of intensive observational and theoretical efforts before a clear understanding will emerge.

There appears to be a common misconception that the ozone layer is a static entity, and that a decrease in the total ozone content, if found, can be taken as evidence that chemicals are causing the depletion. This is far from reality. A look at the observed distribution of ozone column density (total ozone amount per unit area) will soon convince one that dynamical transport plays a very important role in determining ozone's latitudinal and seasonal variations. For example, in the tropics, where most ozone is produced in the presence of abundant sun light, its concentration is actually very low all year round. This ozone minimum is now understood to be caused by the upwelling of ozone-poor air from the lower atmosphere which displaces ozone-rich air away from the Equator in both hemispheres. Maximum ozone concentration is actually found in high latitudes, where one does not expect it to be if one uses purely chemical considerations. In the Northern Hemisphere, this maximum occurs over the Arctic region, with almost twice as much ozone as over the Equator. In the

Southern Hemisphere, the poleward transport is weaker and the ozone maximum occurs over the middle latitudes, instead of going all the way to the pole, as in the Northern Hemisphere.

As temperature changes from season to season and fluctuates from year to year, the air circulation that transports ozone to the high latitudes changes accordingly. The 40% seasonal decrease in column ozone over the Arctic from the spring maximum to fall minimum is a result of such a seasonal change in temperature. Very few in the scientific community would attribute this large seasonal ozone change in the Northern high latitudes to chemical causes. Although there is less agreement on the cause of the Antarctic seasonal decline, also about 40%, our calculation suggested that it too can be accounted for by seasonal circulation changes.

Our computer calculations based on the latest model incorporating coupled dynamics, chemistry and radiation, developed under support from NASA, tell us that ozone content over mid to high latitudes is quite sensitive to year-to-year as well as seasonal temperature changes. Quantitatively, for every 2°C drop in temperature in the lower stratosphere, total ozone content decrease by about 5%. These numbers are consistent with the analysis of ozone and temperature data by Drs. Jerry Mahlman and Steven Fels of Princeton University for the period 1979 to 1985. So the observed 40% decline in Antarctic column density of ozone between 1979 and 1985 can be caused by a 16°C cooling in the lower stratosphere. Such a temperature change has in fact occurred, as reported by Drs. Paul Newman and Mark Schoeberl of NASA in the November 1986 Geophysical Research Letters. I should add, however, that there still exist some uncertanties concerning the accuracy of the measurements and of the models. And again there is no consensus yet in the scientific community.

Our understanding of the chemistry of the Antarctic lower stratosphere has advanced considerably, especially after the National Ozone Expediation this past September and October. As will be discussed by other scientists in more detail today, the chemistry of this part of the atmosphere is found to be highly abnormal, presumably because of the extreme coldness of the region: certain chemicals are present in quantities that cannot be explained with standard chemistry. Since standard chemistry can explain at most 2% of the Antarctic ozone decline instead of the 40% decrease observed, nonstandard chemistry has to be invoked if the Antarctic ozone hole phenomenon is to be accounted for by chemical reactions involving active chlorine released by the CFC's. The findings of the NOZE team suggest that nonstandard chemistry cannot be ruled out. However, we simply do not know, until we have more measurements in the laboratoy and in the field, whether nonstandard chemistry accounts for 50%, or 10%, or 2% of the observed ozone decline in that region.

My own opinion is that the Antarctic ozone will continue to go up in some years and go down in some other years in a more or less zigzag pattern, and a large part of this fluctuation is dynamical in origin. Whether or not there is a small, underlying, long-term chemical trend due to increases in CFC emission cannot be confidently determined at this point unless we can filter out the larger dynamical fluctuations. We do not yet feel we can do this with the accuracy that is required.

The last comment also applies to ozone data from the Northern Hemisphere and even to globally averaged ozone. It is well known that the atmospheric system fluctuates in many time scales: there exist cycles from a couple of years to 40 years or longer. I would advise caution in the interpretation of long-term trends in total ozone.

STATEMENT OF

Dr. Crofton B. Farmer

Earth and Space Sciences Division

Jet Propulsion Laboratory

California Institute of Technology

before the

Subcommittee on Hazardous Wastes and Toxic Substances

Subcommittee on Environmental Protection

Committee on Environment and Public Works

United States Senate

Mr. Chairman and Members of the Subcommittees:

It is a pleasure to be here today to describe the results of the measurements which the group from the Jet Propulsion Laboratory made last year as part of the National Ozone Expedition. I am the Principal Investigator of two ongoing environmental studies, sponsored by the National Aeronautics and Space Administration at the Laboratory, which are concerned with potential perturbations to the Earth's upper atmosphere. The first of these is the Atmospheric Trace Molecule Spectroscopy (ATMOS) investigation, designed to make atmospheric measurements from the Space Shuttle, and the second is a program involving atmospheric measurements from the ground, from aircraft and from stratospheric balloons.

Our purpose in going to Antarctica was to measure the variation with time of many of the minor and trace constituents of the atmosphere over McMurdo Station, and I have prepared a written statement for the record in which the behavior of ten different molecular species, relevant to the chemical stability of the stratosphere, is described. With your permission I will summarize these results, with emphasis on our findings related to the chlorine-containing gases.

A. The Measurements

During September and October, 1986, we recorded a series of high-resolution infrared absorption spectra of the Antarctic atmosphere from a location close to McMurdo Station. The basis of the method is as follows: Each of the constituent gases in the atmosphere absorbs the sun's radiation at its own characteristic frequencies, providing us with an unambiguous signature by which we can identify its presence. From the amount of radiation absorbed, and its change as the sun rises above the horizon, we can determine how much of each gas is present and at what altitudes it resides. To be able to measure, simultaneously, as many different constituents as possible, a wide range of frequencies must be covered, and for this purpose we took to Antarctica a new instrument - a state-of-the-art Michelson interferometer - a type of spectrometer capable of rapidly recording a very large set of frequencies. This complex optical instrument was built specifically for operation under adverse mechanical and thermal conditions, and is similar to the ATMOS instrument which returned a wealth of new upper atmospheric data from its maiden flight on the Shuttle Challenger in May of 1985. Much of the computational facility and basic spectroscopic information required for the analysis of the extensive data set gathered at McMurdo was available as a result of the ATMOS program. The McMurdo spectra covered the infrared frequency range from 600 to 4000 cm-1, or wavelengths from about 2 to 16 micrometers - a range which includes characteristic absorptions of all of the molecular constituents of the atmosphere.

The rationale for the measurements was that observation of the behavior of several key constituents during the period of the development of the seasonal ozone hole and its subsequent recovery, would provide diagnostic indications for discriminating between the theories that had been put forward to explain the phenomenon. The measurements were planned to commence as soon as possible after the first appearance of the sun at the beginning of the austral spring season, and to continue until the stratosphere had returned to its unperturbed state.

The observations were made from a site, located on a ridge close to Scott Base some 2 miles from McMurdo, from which the sun at low elevation could be seen over a maximum range of azimuth angles. The presence of Mt. Erebus to the north prevented the sun from being seen at the site until early September, even though direct sunlight is visible for the first time from higher elevations on Ross Island before the end of August. The first high-quality spectra were recorded on September 8th., when the duration of sunlight was about 1 hour. During the following seven weeks, as the length of daylight and the range of solar elevation angles increased, spectra were recorded as frequently as possible, i.e. when wind and clear sky conditions permitted. A storm which lasted through the first week of October, together with periods of poor visibility on other occasions, reduced the total number of days on which observations could be made during the 7-week period to about 28. These observation periods are summarized in Figure 1, which shows the variation of solar elevation with time and date at the site.

The springtime depletion of ozone commenced during the first week of September and was centered over Eastern Antarctica. For much of the observation period the edge of the ozone "hole" was located close to McMurdo, which caused the observed stratospheric temperature and ozone column to undergo large fluctuations as the position of the ozone hole shifted. Thus the present measurements sampled the polar atmosphere inside the vortex, before and during the period of development of the ozone hole, as well as the warmer region outside. Data from several days through the period of our observations have been analyzed in order to examine the concommitant variation of the total column abundances, or "overburden", of a number of related groups of molecular species whose behavior could be expected to throw some light on the chemical and dynamical processes occurring in the stratosphere at that time. (The term "column abundance" refers to the total number of molecules of an atmospheric constituent in a vertical column of 1 square centimeter cross-section, from the surface to the top of the atmosphere.)

The spectra contain features of a large number of trace molecular constituents of the Antarctic troposphere and stratosphere, many of which are involved in the photochemistry of ozone. In addition to these, the column values of the tropospheric minor gases, N2O and CH4, give an indication of any vertical motion of the atmosphere, and the CO2 features provide an important check on the airmass and geometry corresponding to each spectral scan. For the results presented here, the overhead column amounts of nitric acid (HNO3), hydrochloric acid (HCl), chlorine nitrate (ClONO2), nitric oxide (NO), nitrogen dioxide (NO2), nitrous oxide (N2O), methane (CH4), and ozone (O3), are reported for 14 days between September 8, and October 24th. In addition, the result of a measurement of hydrofluoric acid (HF) on October 12th. is also included.

The analysis method is based on comparison of portions of the spectra, covering small frequency intervals (or "microwindows") containing one or more transitions of a molecule of interest, with synthetic spectra computed for a model atmosphere with the (known) geometric and physical conditions of the observation. The comparison of the spectra uses a non-linear, least-squares fitting program which, together with the spectral display and model manipulation routines, were developed for the ATMOS computing system at JPL. The principal microwindows used in each case are listed in Table 1.

B. Results of the Measurements

The results are summarized in Figures 2, 3 and 4, from which it is evident that the overburdens of the active and reservoir species underwent large fluctuations during the two month period of the observations, the variations in some cases being larger than a factor of two. The short-term variations (i.e., on a time scale of days) are a reflection of the movement of the polar vortex; the slower changes reveal the variations of stratospheric composition in the vortex that accompany the depletion of the ozone. In common with other studies, we have chosen the temperature at the 50 mb level as the characteristic parameter to describe the sampled airmass and against which to examine correlations of the column abundances of the related trace constituents. These temperatures were taken from radiosonde measurements made at McMurdo by the United States Navy during our observing period, and are superimposed on the three figures showing the time variation of the constituent abundances. In the description of the results that follows, the constituents are grouped together into the minor gases, the nitrogen oxides, and the halogenated reservoir species.

Ozone and the Minor Gases. Figure 2 shows the variation of the measured ozone column, together with the minor gases N_2O and CH_4. Our ozone results are in general agreement with those of the three other groups at McMurdo, bearing in mind that each was observing a slightly different airmass in a very non-uniform atmosphere. In view of the degree of variability of the ozone, both spatially and with time, it is important to note that the JPL ozone values were derived from measurements made simultaneously with all of the other gases reported here. The timing of the initial decrease which marks the beginning of the seasonal ozone depletion can be narrowed down to the first week of September, at least as far as the ground-based measurements are concerned; fluctuations of the ozone column throughout the period up to the last week of October occurred in close correlation with the temperature. These variations are the result of the "patchiness" of the lower stratosphere, as Hofmann has described, coupled with the fact that McMurdo was on the edge of the "hole" most of the time, so that measurements which are made from the ground probe the region of the stratosphere where the changes in temperature are the most rapid. Our measurements could not be continued beyond the October 24th., (because we had completely filled our data storage to capacity), by which time there had not been any sign, from the McMurdo total column observations at least, that a recovery in the ozone column had begun to take place. Indeed, as far as our own measurements were concerned, the lowest ozone value was recorded only three days earlier, on October 21st. The TOMS (satellite) measurements show the recovery beginning during the last week of October.

In contrast to the ozone column and the temperature, which underwent large changes, the column values for the tropospheric minor gases, N_2O and CH_4, remained constant, except for a 10% perturbation between October 8th. and 15th. The surface pressure showed a relatively large fluctuation at the same time. At mid-latitudes CH_4 and N_2O have vertical distributions which are characterized by uniform mixing in the troposphere, with a fairly rapid decrease above the tropopause. The McMurdo spectra showed that the distributions of these gases in the Antarctic atmosphere were similar to their profiles at lower latitudes, but with approximately 10% smaller total column amounts, as expected for the polar atmosphere with its lower tropopause altitude and surface pressure. Both the constancy of the column values of these two gases through the changes of the sampled airmasses, as well as their reduced absolute column amounts, argue against any reversal of the vertical motion of the atmosphere within the polar vortex.

Nitrogen Species. Figure 3 shows the results for the three nitrogen species HNO_3, NO and NO_2. The HNO_3 values exhibit the closest correlation with the stratospheric temperature of all of the gases that were monitored. The relationship between the the nitric acid vapor abundance and temperature is an indication of the possible presence of a condensed phase. The zenith angle variation of the absorptions shows the nitric acid to be distributed some 10 km lower in the polar region than it is at mid-latitudes. The column abundances, which are plotted at half-scale in Figure 3, are larger by a factor of two than the corresponding amounts at lower latitudes. It should be noted also that, while there are large-amplitude fluctuations in the amount of HNO_3, there is a clear decreasing trend with time through the two month period.

The NO column values increasd slightly from September to mid-October, the mean value of about 3x10**15 cm-2 being the same as that at mid-latitudes. The NO_2 values were found to be very low at the beginning of the observation period, falling below the detectable level by the third week of September, and then increasing to a maximum of 3.5x10**15 cm-2 towards the end of October. The corresponding daytime NO_2 column value at mid-latitudes is almost double the maximum value observed over McMurdo so that, bearing in mind the 8 or 10 km lower altitude of its distribution, the peak mixing ratios of the polar NO_2 are considerably reduced during this period in comparison with mid-latitudes.

Halogen Sinks and Reservoirs The behavior of the principal chlorine reservoirs, hydrochloric acid (HCl) and chlorine nitrate ($ClONO_2$), is shown in Figure 4. The HCl column amounts, which are derived from the analysis of several strong absorption lines, show a steady increase from an initial low value of 1.6x 10**15 cm-2, to 4.1x 10**15 cm-2 by mid- October. A further rapid increase to 5.4x10**15 cm-2 occurred during the last few days of observation, an almost fourfold increase overall. The corresponding column value for the stratospheric component of HCl at mid-latitudes is 1.5x 10**15 cm-2.

The $ClONO_2$ results show a similar trend (but with much larger day-to-day variations) until the begining of October, after which there is a marked reversal and the column amounts decrease for the remainder of the period. The polar $ClONO_2$ column values are considerably higher, with respect to mid-latitude amounts, than is the case for HCl. The question of the partitioning of chlorine between these two species is discussed later. The variation of the total amount of chlorine in the reservoirs (which is assumed to be the sum of HCl and $ClONO_2$) is also plotted in Figure 4; this shows a very close correlation with the stratospheric temperature and an increase of the total vapor phase chlorine of a factor of two between September and October.

The sink for fluorine, hydrofluoric acid (HF), was measured on one day only, towards the end of the observing period at McMurdo, because the wavelength of the absorption band of HF lies outside the normal range of the primary optical filter used; this requires changing the filter, a difficult task under the conditions at the observing site. The spectra that were obtained for HF were of very high quality and the derived column abundance, 1.8x10**15 cm-2, has an estimated accuracy of 5%. The importance of this measurement in the context of validating the chlorine column values is discussed below.

C. Discussion

The constant values of the column abundances of the tropospheric minor gases N_2O and CH_4 throughout the two month period, at approximately 90% of their mid-latitude values, are inconsistent with a model of the polar circulation in which upward motion carries tropospheric, ozone-depleted, air into the polar vortex.

The NO_2 abundance is severely depleted in September and increases in October to a maximum value which does not exceed the NO_2 column at mid-latitudes. The values for NO, which is located at higher altitudes, show a small increase (of about 30%) between September and October, the overall mean value being in close agreement with current mid-latitude column values. There appears to be no indication of the enhanced levels of nitrogen oxides required by ozone depletion mechanisms based on postulated increased solar activity.

When discussing the sinks and reservoir species it should be borne in mind that the measurements themselves yield values for only the vapor phase abundances of the constituents. The increase in the chlorine reservoirs between September and October requires either that substantial fractions of the HCl and $ClONO_2$ are held in some condensed form (for example, as PSC's) during the late winter/early spring months, or that "missing" chlorine is present in the atmosphere in some other molecular form which we have not yet been able to identify in the spectra. The former possibility is supported, in a qualitative sense, by the close correlation of the reservoir species (including HNO_3) with the stratospheric temperature. In the absence of significant condensation, however, the deficit to be made up by an alternate molecular form of chlorine is large - at least 4x10**15 cm-2 - and species with even the weakest oscillator strengths would be readily detected at the high signal-noise ratio of these observations, unless their absorption bands coincided with opaque regions of the spectrum; (strong methane and nitrous oxide lines, for example, hamper the search for Cl_2O_2 in the 1200 cm-1 region of the spectrum). The minimum column amount of ClO that could be detected in the spectra is conservatively estimated to be between 1 and 2x10**15 cm-2. The present results taken alone, therefore, do not preclude the possibility that relatively large amounts of ClO, but less than 2x10**15 cm-2, are present in the stratosphere during September and early October. The missing chlorine cannot be accounted for by ClO alone, however.

In either of the above cases, the partitioning of chlorine between $ClONO_2$ and HCl is unusual, and very different from the observed situation at lower latitudes, where measurements and model predictions are in good agreement. The mid-latitude column values for $ClONO_2$ and stratospheric HCl are 7x10**14 and 1.5x10**15 cm-2, respectively. By comparison, the corresponding values for McMurdo in October were approximately 4x10**15 cm-2 for each species. The partitioning between the two reservoirs reverts to a ratio more typical of lower latitudes towards the end of October, at about the same time as the ozone column begins to recover. Thus it is evident that the chlorine chemistry of the Antarctic stratosphere is perturbed during the early spring season.

The measurement of hydrofluoric acid vapor (HF) provides a key reference point in assessing the validity of the Antarctic halogen budget suggested by these results. Man-made chemicals are the only known source of fluorine in the atmosphere and HF in the stratosphere is the direct result of the photolysis of CFC's. The column abundance of HF at McMurdo (1.8x10**15 cm-2) is, as expected, some three times larger than the corresponding value at mid-latitudes, a consequence of the stratospheric circulation and the long lifetime of HF. The HF features in our spectra are among the clearest and highest quality for quantitative analysis, so that high confidence in the HF column value derived for McMurdo is justified. The ratio of HF/HCl in the upper stratosphere is important in understanding the effects of injection of halogenated chemicals since it resolves the complication that arises because chlorine has natural as well as anthropogenic sources, coupled with the fact that HCl is removed more easily from the atmosphere than is HF. The ratio of fluorine to chlorine (HF/HCl) in the upper stratosphere at mid-latitudes is presently 1/4, a value which has increased from 1/10 over the 10 years since we first measured its distribution. From the McMurdo measurements the fluorine to chlorine ratio for the Antarctic stratosphere was found to be close to 1/4 also, after the total chlorine (taken here as the sum of ClONO2 and HCl) had reached its maximum value (i.e., from the second week of October on). This ratio remained constant through the end of the observation period, even though the partitioning between the two forms of chlorine changed markedly (with ClONO2 being converted to HCl). This suggests that by mid-October all of the chlorine was in the vapor phase with very little of it being in any form other than HCl or ClONO2.

Finally, we conclude that:

(i) neither the dynamical nor the solar activity explanation for the ozone depletion is supported by the evidence found in our measurements;

(ii) the close correlation between the stratospheric temperature and the vapor phase abundances of the reservoir species substantiates the role of heterogeneous processes in the polar stratospheric chemistry; and

(iii) while the temporal behavior of the partitioning of chlorine among its chemical reservoirs is not proof of a cause and effect relationship between halogenated source gases and the springtime ozone depletion, it is, nevertheless, entirely consistent with such an explanation.

D. Future Measurements

The disadvantage of a fixed location, such as McMurdo, for these measurements is that the air inside the ozone hole can be sampled only when and if the vortex moves towards the observation site. In 1986 we were fortunate that this occurred twice during the period of our measurements and that the weather conditions were favorable on both occasions. From an aircraft, on the other hand, we have control over when and where we choose to sample the atmosphere; consequently, our plan for the 1987 season is to mount our instrument in the NASA DC 8, which will make flights over Antarctica from southern Chile.

This opportunity will provide additional benefits by virtue of the higher altitude at which the observations are made, the principal advantage being the improved accuracy to which stratospheric constituents can be monitored. Of particular importance in this regard will be the ability to measure other expected chlorine-containing molecules, e.g. Cl2O2, which are not detectable from the ground, due to interference from tropospheric gases. A further advantage is that measurements can be made earlier in the season, because the sun is higher above the horizon as seen from an aircraft. This may provide important clues to the precise chemical mechanisms which cause the ozone hole.

May 12, 1987

Table 1 Principal Microwindows used for Analysis

Constituent	Central Frequency and Width (cm-1)
CO2	2632.4, 2636.6 (0.2)
H2O	1959.6 (1.0), 3155.4 (1.5), 3231.4 (0.4)
O3	1154.6 (0.4)
N2O	1194.0 (0.8)
CH4	2671.3 (0.8)
HNO3	868.0 (4.0)
ClONO2	780.2 (0.3)
NO	1900.1, 1903.2 (0.2)
NO2	2914.6 (0.3)
HCl	2843.6, 2925.9, 2963.3 (0.2)
HF	4038.9 (0.2)

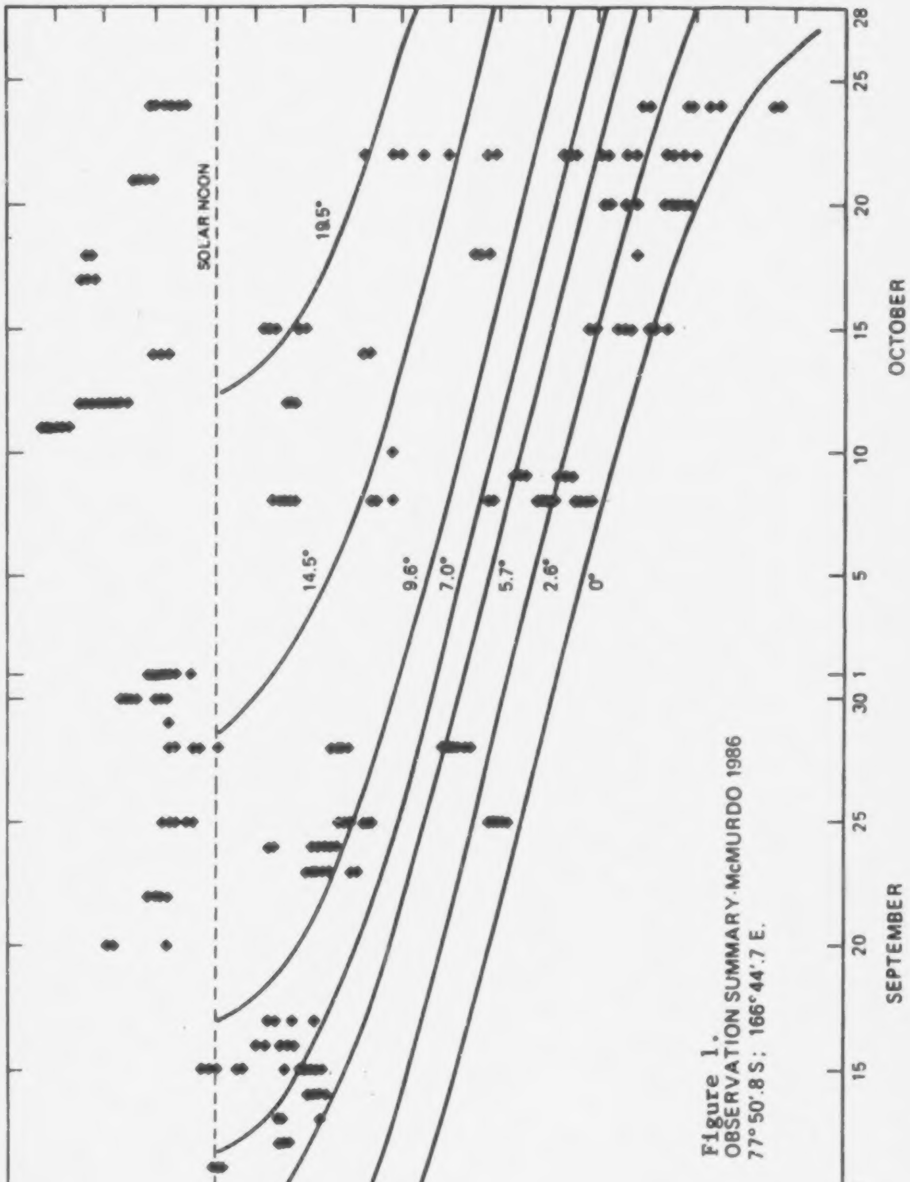

Figure 1.
OBSERVATION SUMMARY McMURDO 1986
77° 50'.8 S; 166° 44'.7 E.

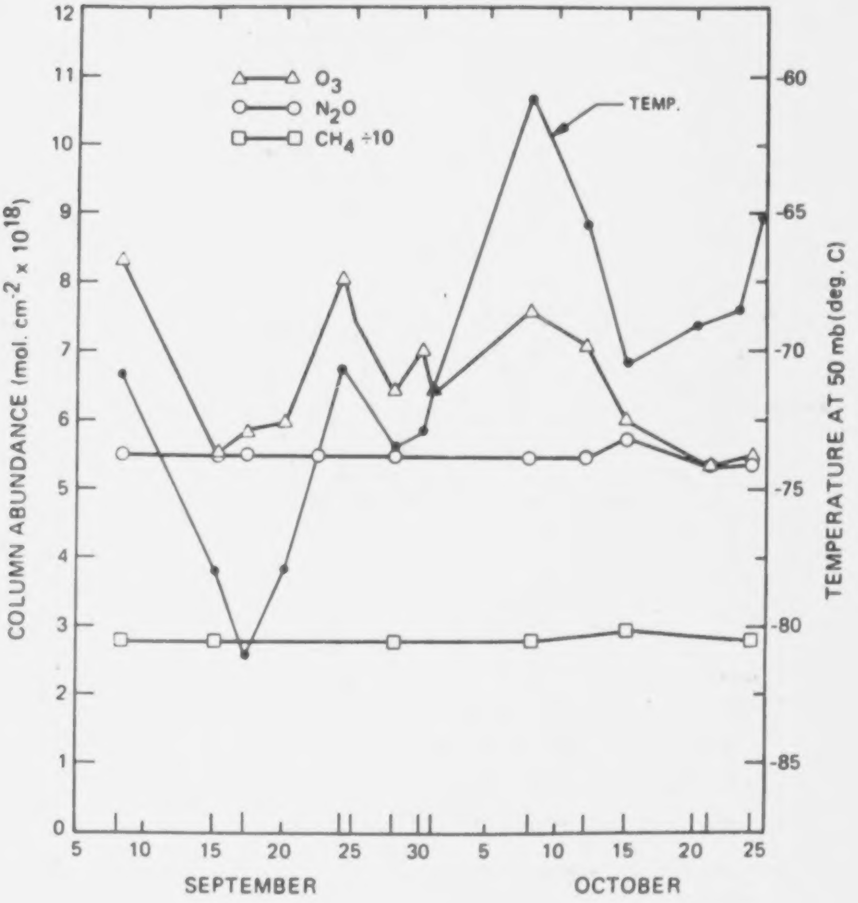

Figure 2. Vertical column abundances of ozone and the minor gases N2O and CH4 over McMurdo Station during September and October, 1986. The temperature at the 50 mb level (about 20 km altitude) is also shown.

C. B. Farmer
Jet Propulsion Laboratory
May 1987, unpublished data

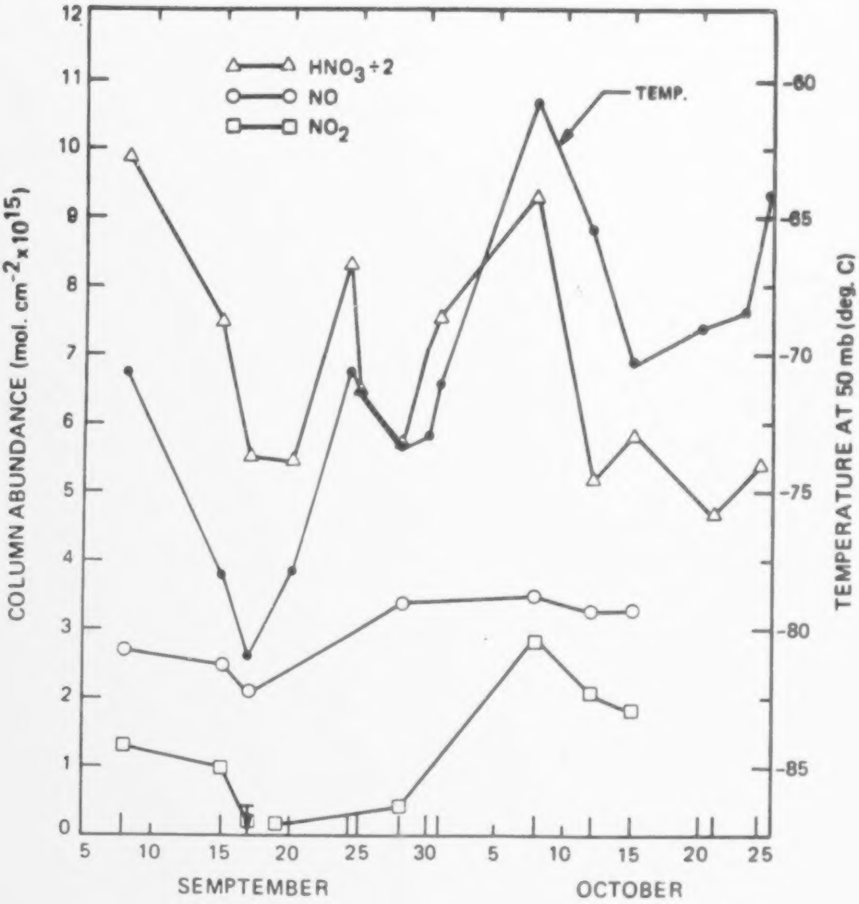

Figure 3. As Figure 2, for HNO3, NO and NO2

C. B. Farmer
Jet Propulsion Laboratory
May 1987, unpublished data

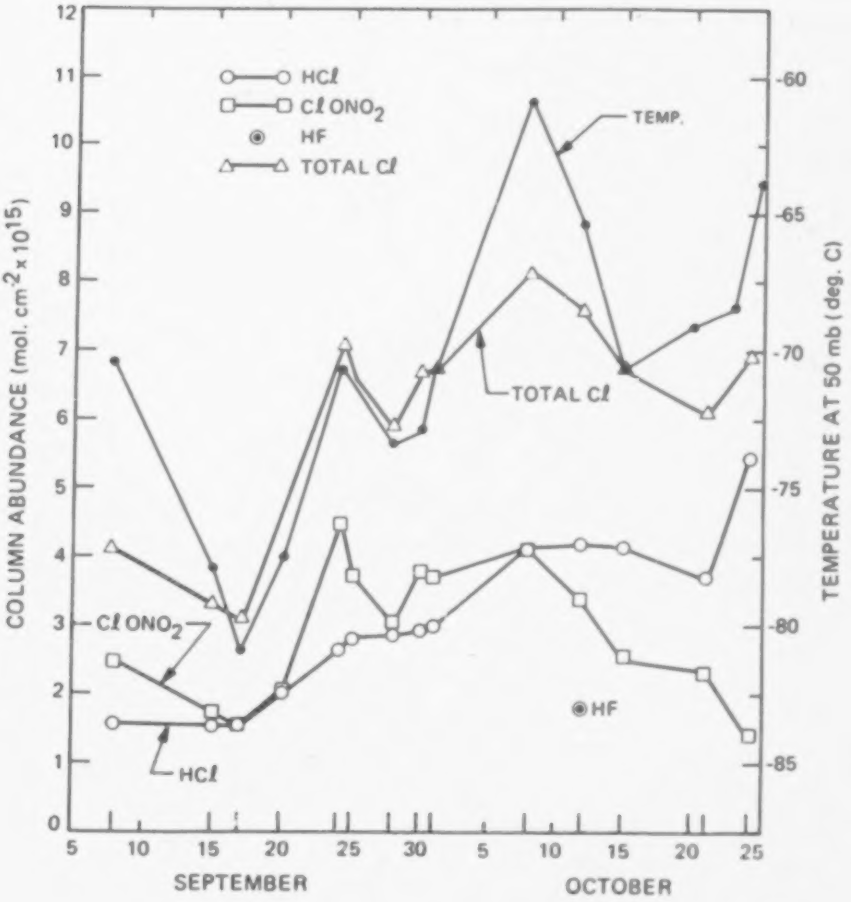

Figure 4. As Figure 2, for the chlorine reservoir molecules HCl and ClONO2. The column value for HF is also shown.

C. B. Farmer
Jet Propulsion Laboratory
May 1987, unpublished data.

TESTIMONY OF
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METEOROLOGICAL CHEMISTRY GROUP
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ENVIRONMENTAL RESEARCH LABORATORIES
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

BEFORE THE

SUBCOMMITTEE ON ENVIRONMENTAL PROTECTION
AND
SUBCOMMITTEE ON HAZARDOUS WASTES AND TOXIC SUBSTANCES
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
UNITED STATES SENATE

MAY 12, 1987

Mr. Chairmen and Members of the Subcommittees:

As project scientist for the NASA/NOAA/NSF/CMA ER-2 & DC-8 aircraft mission to investigate the Antarctic ozone hole in August and September of this year, I welcome the opportunity of explaining our goals and plans to you.

After some preliminary discussion in mid-1986, it was realized that the suite of experiments which had, over several years, been fitted on the NASA ER-2 high altitude research aircraft for the Stratosphere Troposphere Exchange Project (STEP) was well suited for investigating some features of the Antarctic ozone hole. With the addition of an experiment to measure key ozone-related chemical species, chlorine and bromine monoxide, ClO and BrO, and with further supplementation by instruments designed to measure tracers of atmospheric motions, the ER-2 became a tool with powerful potential for investigating current theories of the ozone hole, both chemical and dynamical.

The ER-2 measurements are essentially local, confined to the flight path of the aircraft.

When planning began in earnest in August 1986, it was realized that the mission would be greatly enhanced if NASA's DC-8 aircraft could be fitted with a set of four remote sounding instruments, to measure ozone and aerosol profiles by lidar, and column abundances of a number of other ozone-related molecules, by passive remote sounding. These latter instruments are airborne versions of the instruments used by the NOZE expedition at McMurdo last year, plus another instrument with a decade of successful aircraft operation behind it. In addition, there are three in situ instruments, to measure ozone, water vapor and other constituents in air; these are useful because the DC-8 will be flying at altitudes near the lower extremes of the ozone hole.

The scientific questions, and the aircraft payload components which will seek to answer them, are summarized on two pages appended at the back of this testimony.

Operational plan, August-September 87

The airfield selected, because it is the only one suitable for flights over Antarctica, is Punta Arenas in Chile (53°S, 71°W), located on the Magellan Strait just north of Cape Horn. The mission is a considerable logistical undertaking involving over 100 personnel on site, with a support C141 aircraft for shipment of scientific equipment and personnel connected with the ER-2, plus a large seaborne shipment of material.

The weather will pose some potentially severe problems, given the ER-2's susceptibility to side winds on take-off and landing, and to temperatures below -85°C (-95°C or colder will probably be experienced at cruise altitudes in the polar vortex during August and early September). Meteorological forecasting is therefore vital for reasons of aircraft safely, as well as being essential for achieving the scientific aims associated with flying into the ozone hole. The numerical weather prediction products, and near real-time maps of total ozone over Antarctica from the TOMS satellite instrument, plus an attempt to do near real-time photochemical modelling along air parcel trajectories, together imply an expensive telecommunications network to get the information from the large mainframe computers in the US and the UK to Punta Arenas. Schematic diagrams of the disposition of personnel and hardware are appended.

Meteorologically-guided flight tracks

In any experiment where spatial or temporal change of a stratospheric chemical species is observed, the first question to be asked is whether it can be attributed to chemical or meteorological processes, or both. To resolve the ambiguity in separating the effects of chemistry and dynamics, it is hoped to follow the chemical evolution of the same parcels of air, by flying in them more than once. This is to be done by using forecast trajectories of air parcels sampled on previous flights. This technique, recently developed for use with satellite data in the Northern Hemisphere, has not been used for aircraft work before. Nevertheless, simulation in previous Septembers suggests a recurrence time for air parcels over the Antarctic Peninsula of 2-8 days, depending on latitude. By feeding back the aircraft data to a theoretical photochemical model that calculates the chemical processes along the air parcel trajectories, it is hoped to get scientific insight into the results much more quickly than is normal in an airborne mission, and we hope that this insight will occur in time to improve the skill with which the later flights are conducted. There will also be a small theoretical team at Punta Arenas to supplement the efforts of the instrumental principal investigators in seeking to understand the results as they come in.

The ER-2 is confined to the Palmer Peninsula region, will fly up to 18-19 km, which is well into the stratosphere, and can penetrate southward to a latitude of about 72°S. The DC-8 on the other hand has the capability to fly to the South Pole and then on the Christchurch, New Zealand. It is hoped to mount two such long flights in which a vertical section is taken across the entire polar vortex; ideally, one of these should be when the "ozone hole" is nearly symmetric about the pole, the other when it is in a distorted configuration.

Summary

Despite a very tight schedule, particularly for the DC-8, the project is currently on track to achieve its goal of 10-12 flights per aircraft from August 17th to September 28th of this year. This is largely because of the magnificent cooperation received en route from all concerned, and the "can do" attitude of those responsible for the aircraft engineering and for implementation of the logistics and telecommunications. However, there are crucial test flight series upcoming through June and July at NASA Ames and there is no doubt that the Cape Horn-Antarctic weather, e.g., high winds and cold temperatures at cruise altitude, can pose major problems.

Nevertheless, as the following two pages show in summary, the aircraft will have instrumental payloads capable of providing good quality information, well resolved spatially, on many of the physical and chemical quantities thought to be involved in the "ozone hole".

Thank you for your interest and attention; I will do my best to answer any questions you may have.

SCIENCE QUESTIONS

1. Is there sufficient ClO to sustain a fast enough non O-atom reaction chain or chains that lead to ozone depletion?

2. What is the extent of Br and BrO involvement in ozone depletion?

3. What is the morphology of the ozone depletion?

4. What are the spatial and temporal correlations of O_3 with Cl_x, NO_y, and polar stratospheric clouds?

5. What are the compounds that makeup NO_y?

6. What is the water vapor mixing ratio?

7. What is the extent, temperature-dependence, size distribution and chemical composition of particulate matter?

8. How aged (what is the fraction of recent tropospheric origin) is the air in the cold pool beneath the polar vortex?

9. Is there a coherent pattern to the vertical velocities of air motions?

- -

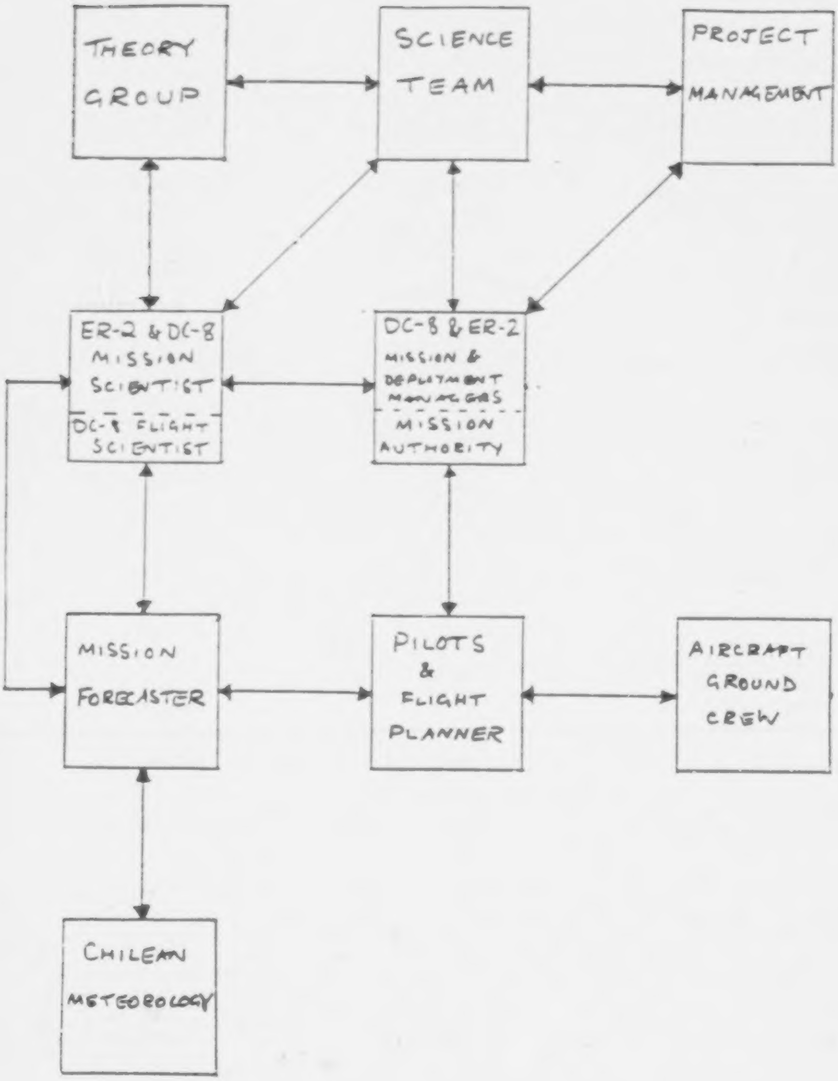
10. If spatial or temporal changes in ozone are detected, can the effects of chemistry and dynamics be separated?

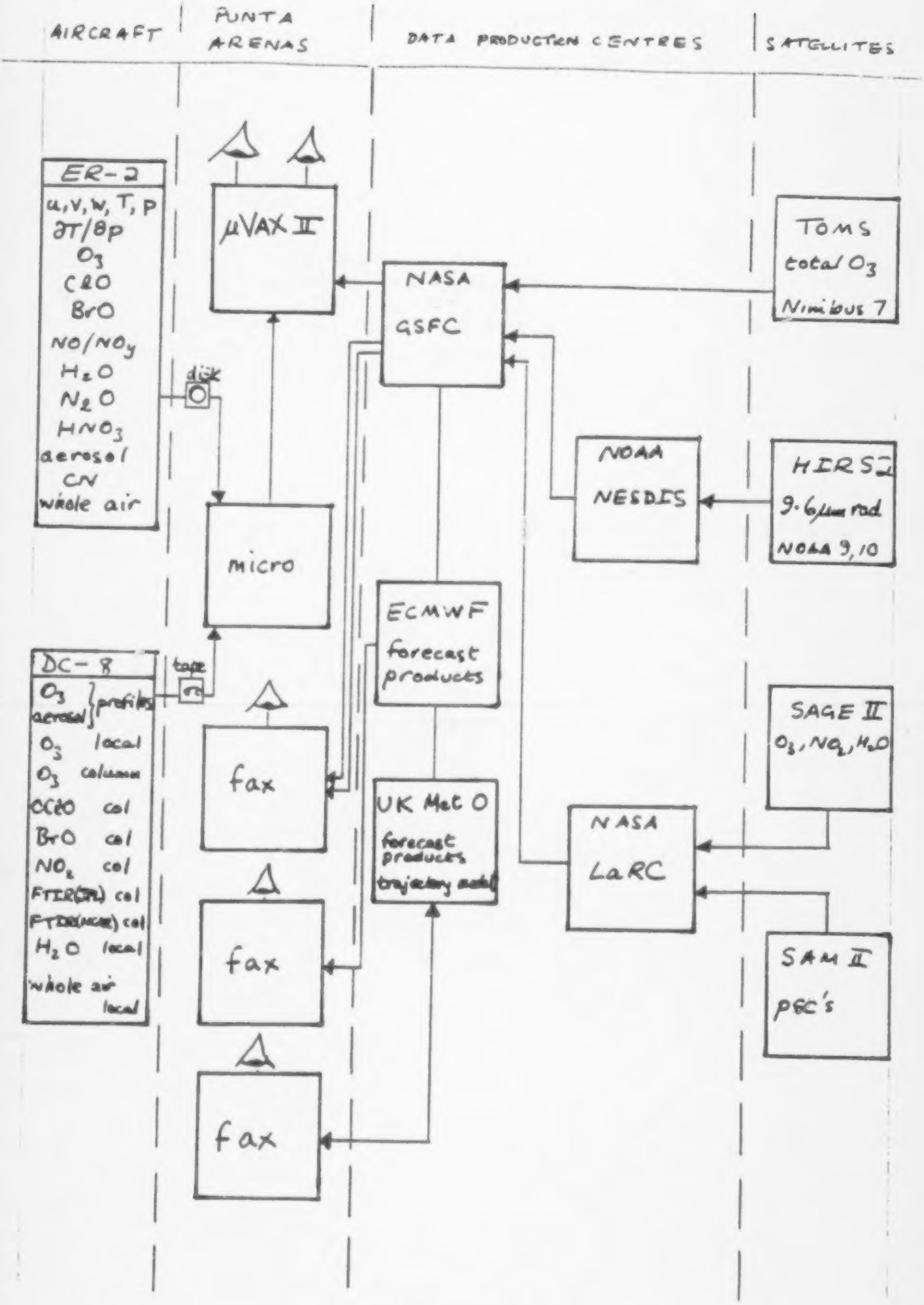
11. To what extent is the assumption of air parcel integrity justified?

MISSION ANSWERS

1.	Anderson (Harvard)	ClO	local ER-2
	Wahner (NOAA AL)	OClO	column DC-8
	Farmer (JPL)	$ClONO_2$, HCl, ClO?,HOCl?	column DC-8
	Mankin/Coffey (NCAR)	HCl	column DC-8
2.	Anderson (Harvard)	BrO	local ER-2
	Wahner (NOAA AL)	BrO	column DC-8
3.	Browell (NASA Langley)	O_3	profile DC-8
	Farmer (JPL)	O_3	column DC-8
	Coffey/Mankin (NCAR)	O_3	column DC-8
	Wahner (NOAA AL)	O_3	column DC-8
	Gregory (NASA Langley)	O_3	local DC-8
4.	Proffitt (NOAA AL)	O_3	local ER-2
	Starr (NASA Ames)	O_3	local ER-2
	Fahey (NOAA AL)	NO or NOy	local ER-2
	Wilson (DU)	aerosol	local ER-2
	Ferry (NASA/Ames)	aerosol	local ER-2
	Browell (NASA Langley)	aerosol	profile DC-8
	Farmer (JPL)	O_3, several	column DC-8
	Mankin/Coffey (NCAR)	O_3, several	column DC-8
5.	Farmer (JPL)	NO, NO_2, HNO_3	column DC-8
	Coffey/Mankin (NCAR)	NO, NO_2, HNO_3	column DC-8
	Gandrud (NCAR)	HNO_3	local ER-2
	Wahner (NOAA AL)	NO_2	column DC-8
6.	Kelly (NOAA AL)	H_2O vapor (?)	local ER-2
		H_2O total	local DC-8
	Farmer (JPL)	H_2O	column DC-8
	Mankin/Coffey (NCAR)	H_2O	column DC-8
7.	Wilson (DU)	0.01-1.0 μm	local ER-2
	Ferry (NASA/Ames)	0.1-3.0 μm	local ER-2
	Gandrud (NCAR)	chemical composition	local ER-2
	Oberbeck/Pueschel (NASA Ames)	chemical composition	local ER-2
	Browell (NASA Langley)	vertical profile ~1μm	profile DC-8
8.	Loewenstein (NASA Ames)	N_2O	local ER-2
	Heidt/Vedder (NCAR/Ames)	whole air CH_4, N_2O, CO, CFC's	local ER-2 &DC-8
9.	Chan (NASA Ames)	U, V, W, T, p	local ER-2

10.	Jones (UK Met O)	Lagrangian photochemistry model	
11.	Chan (NASA Ames)	U, V, W, T, p	local ER-
	Gary (JPL)	$\partial T/\partial p$	local ER-2
	Heidt/Vedder (NCAR/Ames	whole air	local ER-2 &DC-8


THEORY GROUP
SCIENCE TEAM
PROJECT MANAGEMENT
ER-2 & DC-8 MISSION SCIENTIST
DC-8 FLIGHT SCIENTIST
DC-8 & ER-2 MISSION & DEPLOYMENT MANAGERS
MISSION AUTHORITY
MISSION FORECASTER
PILOTS & FLIGHT PLANNER
AIRCRAFT GROUND CREW
CHILEAN METEOROLOGY


AIRCRAFT
PUNTA ARENAS
DATA PRODUCTION CENTRES
SATELLITES
ER-2
u, v, w, T, p
∂T/∂p
O3
ClO
BrO
NO/NOy
H2O
N2O
HNO3
aerosol
CN
whole air
disk
μVAX II
micro
DC-8
O3
aerosol
profiles
O3 local
O3 column
OClO col
BrO col
NO2 col
FTIR(JPL) col
FTIR(NCAR) col
H2O local
whole air local
tape
fax
fax
fax
NASA GSFC
ECMWF
forecast products
UK Met O
forecast products
trajectory model
NOAA NESDIS
NASA LaRC
TOMS
total O3
Nimbus 7
HIRS 2
9.6μm rad
NOAA 9, 10
SAGE II
O3, NO2, H2O
SAM II
PSC's

POTENTIAL EFFECTS OF INCREASED
UVB RADIATION ON THE IMMUNE SYSTEM

Margaret L. Kripke, Ph.D.
Vivian L. Smith Chair in Immunology
Professor and Chairman, Department of Immunology
University of Texas
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United States Senate Committee on Environment and Public Works

Hearing on Stratospheric Ozone Depletion

May 12, 1987

INTRODUCTION

Increases in the amount of solar UVB radiation reaching the earth's surface are expected to result in a variety of effects on biological and atmospheric systems. The potential effects on human health identified to date are 1) increases in the incidence of cancers of the skin, 2) increases in the incidence of cataracts, and 3) alterations of the immune system. During its review of the EPA's risk assessment document on stratospheric modification, the EPA Science Advisory Board's Stratospheric Ozone Subcommittee attempted to prioritize these effects in terms of their potential global impact and current state of knowledge. As shown in Table 1, the current state of our knowledge on the possible immunological effects of increased UVB radiation is very low, but the potential significance of these effects for human health could be quite high.

Table 1

Potential Effects of Increased UVB Radiation Resulting from Decreased Stratospheric Ozone[1]

Effects	State of Knowledge	Potential Global Impact
Skin Cancer	Moderate to high	Moderate
Immune System	Low	High
Cataracts	Moderate	Low
Plant Life	Low	High
Aquatic Life	Low	High
Climate Impacts*	Moderate	Moderate
Tropospheric O_3 and H_2O_2	Moderate	Low
Polymers	Moderate	Low

*Contribution of O_3 to climate changes, including sea level rise

[1] Taken from SAB-EC-87-025 "Review of EPA's An Assessment of the Risks of Stratospheric Modification by the Stratospheric Ozone Subcommittee, Science Advisory Board, U.S. Environmental Protection Agency, March, 1987.

The combination of a small amount of information along with a potentially high global impact means that we do not presently know whether increased UVB radiation will adversely affect the functioning of the immune system, but if it does, the consequences could be of major significance for human health.

Thus, the reason for concern about what UVB might be doing to the immune system is that we do not have sufficient information in order to answer this question. The areas in which we need more information are the ability of UVB radiation to interfere with immune responses to sunlight-induced skin cancers, other types of skin cancers, and infectious organisms. Of primary importance is the question of whether increased UVB could increase the incidence or severity of any infectious diseases.

IMMUNOLOGICAL EFFECTS OF UVB ON LABORATORY ANIMALS

Effects related to skin cancer.

The motivation for asking whether UVB exposure can modify the human immune system comes from studies of the effects of UV radiation on animals. More than ten years ago, we discovered that exposing mice to UV rays caused a systemic change in their immune system that contributed to the development, growth, and spread of UV-induced skin cancers.

We now know that the systemic change brought about by UVB irradiation involves the production of suppressor lymphocytes. These cells are part of the immune system, and they are involved in regulating the magnitude and duration of an immune response. The suppressor lymphocytes present in mice exposed to repeated doses of UVB radiation actually prevent the development of an immune response against UVB-induced skin cancers. The effect of these UVB-induced suppressor lymphocytes, then, is to suppress the body's natural defense mechanisms against UV-induced skin cancers.

There is also some evidence suggesting that the systemic effects of UVB irradiation could increase the incidence or growth rate of some other kinds of skin cancers, including malignant melanoma. Furthermore, there is one report indicating that the incidence of leukemia is elevated in UV-irradiated mice. However, there is no evidence at present suggesting that cancers of other organs are affected by UV-irradiation of the host.

Effects on other immune reactions.

It is now known that exposure of animals to UVB radiation can suppress several other types of immune reactions, in addition to the immune response against skin cancers. Mice treated with very low doses of UVB radiation, on the order of three or four minutes, do not make a contact allergy reaction to chemicals applied through the irradiated skin. Instead, suppressor lymphocytes are formed. There is considerable evidence that the UV rays damage a type of immune cell found in the skin (the Langerhans cell), and that this damage leads to activation of suppressor lymphocytes, instead of the appropriate immune response. Thus, although the initial damage is localized to the area of skin exposed to the UV radiation, the resulting immunological suppression is systemic, because the suppressor cells circulate throughout the body.

With higher doses of UV, on the order of three or four hours of exposure, UV-irradiated animals lose their ability to respond to chemicals applied through the unexposed skin. They also have a decreased lymphocyte-mediated response to foreign substances injected under the skin (delayed hypersensitivity reaction). In both instances, the immunosuppression again seems to be due to the formation of suppressor lymphocytes. This systemic effect of UV radiation has been demonstrated to occur in more than one species (mice, rats, and guinea pigs), to be produced with natural sunlight, to be due mainly to wavelengths in the UVB region of the spectrum, and to increase in proportion to increasing doses of UV radiation.

Effects on infectious diseases.

The studies on suppression of certain lymphocyte-mediated immune reactions following UV irradiation raise the possibility that the immune response to infectious agents might also be impaired in this manner. Some disease-producing organisms, such as the parasite Schistosoma and the leprosy bacillus, gain entry into the body through the skin. It is possible that the entry of such organisms through UV-damaged skin might lead to activation of suppressor lymphocytes, instead of an immune response that would combat the infection.

Other infectious agents, including viruses, bacteria, and fungi, produce disease within the skin, and in addition, many organisms normally are controlled by the delayed hypersensitivity type of immune response. In both instances, the systemic immune suppression resulting from UVB-irradiation might increase the severity of the disease process and prevent the development of immunity against reinfection.

To date, only two infectious agents have been studied with regard to their effects in UV-irradiated animals. Howie and colleagues in England showed that injection of Herpes simplex virus under the skin of mice exposed to UVB radiation resulted in a suppressed immune response against the virus. Suppression of immunity against the virus persisted for several months. The effect of the suppression on systemic disease and viral reinfection is not yet known. In this country, Gianinni has shown that infection of UVB-irradiated mice with the protozoan parasite Leishmania fails to induce the protective delayed hypersensitivity immune response found in unirradiated animals. This immune suppression is associated with persistence of the parasite within the body and an inability of the host to control infection. Both of these organisms can cause disease in humans.

IMMUNOLOGICAL EFFECTS OF UVB IN HUMANS

Studies with experimental animals have raised the obvious questions of whether exposure of humans to UVB radiation from natural sunlight, from tanning devices, or from phototherapy for skin disease causes immunological changes of the type seen in animals, and whether such changes are important in the development of skin cancers. There is increasing evidence that such exposures to light containing UVB rays does indeed produce immunologic alterations. For example, exposing human skin to UVB radiation damages the Langerhans cells in the skin in a manner similar to that described in mice. In one study by Hersey and colleagues in Australia, the contact allergic reaction to foreign material applied through UV-irradiated skin was depressed. This result is also analogous to the findings in UVB-irradiated mice, and it implies that the alteration in Langerhans cells is an indicator of functional immune suppression.

There are now several additional reports of immunological changes following exposure of human subjects to UVB radiation or sunlight. These changes include alterations in the number and proportions of various immune cells in the blood, a decrease in the activity natural killer cells (leukocytes that can kill cancer and virus-infected cells), and an increase in the number and activity of suppressor lymphocytes. Most of these alterations were reversible within two weeks after irradiation, but some persisted for a longer period. A recent study by Hersey and colleagues shows that sunscreens do not necessarily protect against these immunological effects of exposure to UV radiation.

Other investigations point to the importance of the immune system as a defense against certain forms of skin cancer. In organ transplant patients, who receive immunosuppressive drugs to prevent graft rejection, the incidence of skin cancer on sun-exposed parts of the body is dramatically increased. Also, the incidence of certain types of skin cancer is elevated in patients with AIDS, a disease characterized by profound immune suppression. These findings suggest that the immune system normally plays a protective role in preventing some skin cancers. Alteration of the immune system by exposure to UVB radiation could thus be expected to exacerbate skin cancers of this type. However, there is at present no epidemiologic or experimental evidence linking UVB-induced immunosuppression in humans with the development of skin cancers other than those caused by direct sunlight exposure. With regard to sunlight-induced skin cancers, we found that Langerhans cells in the vicinity of sunlight-induced basal cell skin cancers resemble those damaged by UVB radiation, providing a link between UV radiation, cutaneous immune cells, and skin cancer. A recent report by Frentz from Denmark suggests that patients with multiple sunlight-induced skin cancers have an increase in the proportion of suppressor lymphocytes in their circulation, compared to patients with multiple skin cancers induced by X-rays.

At the present time, it is not known whether these immunologic effects of UV radiation on humans interfere with the development of resistance to skin or other types of cancer or to immunity against infectious diseases. However, sunlight exposure is known to trigger active herpes virus infection, some allergic reactions, and an autoimmune disease called systemic lupus erythematosis. There are a few reports indicating that UV exposure may exacerbate certain infectious skin diseases in humans.

CONCLUSIONS

It is clear that exposure of animals to UVB radiation suppresses the activity of the immune system against UV-induced skin cancers and against other foreign substances. There is also evidence suggesting that UV exposure may increase the growth or spread of other skin cancers, including malignant melanoma. Exposure of animals to UVB radiation can modify the immune response to the two infectious organisms studied, but the significance of this effect for the disease processes is not yet known.

In humans, various components of the immune system are changed after exposure to natural and artificial sources of UV radiation. These effects are likely to be due to wavelengths in the UVB region of the spectrum, but this has not been proven. Whether these changes are important for the development of sunlight-induced skin cancers is not certain, but there is increasing evidence that this may be so. It should be noted that establishing a link between the immunosuppressive effects of UVB and sunlight-induced skin cancer will probably not alter the current predictions for increases in the incidence of sunlight-induced skin cancer resulting from increased UVB exposure; however such information would help us understand the disease and may suggest new approaches for treatment.

On the other hand, establishing a link between the immunologic effects of UVB exposure and other cancers or infectious diseases could significantly change our estimates of the consequences of increased UVB exposure for human health. In addition, the suggestion from studies in both humans and animals that sunscreens, while preventing sunburn and skin damage, may not protect against immunological changes is an important issue that needs further study. If this suggestion is correct, then the concept that individuals can protect themselves from the hazardous effects of sunlight exposure by the judicious use of the currently available sunscreens will have to be reevaluated.

TESTIMONY OF:

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Massachusetts General Hospital
Wigglesworth Professor of Dermatology and Chairman
Department of Dermatology
Harvard Medical School
Boston, MA.

SENATE COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
SUBCOMMITTEE ON HAZARDOUS WASTES AND TOXIC SUBSTANCES AND
SUBCOMMITTEE ON ENVIRONMENTAL PROTECTION
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HUMAN HEALTH EFFECTS OF DAMAGING ULTRAVIOLET RADIANT ENERGY

I. Introduction: Sunlight and Humans

II. Ultraviolet B (300-320 nm) is the most damaging to humans

III. Ozone depletion → increased UVB intensity → skin cancer

IV. The present melanoma skin cancer epidemic which affects young and middle adults is not due to ozone depletion

V. Melanoma skin cancer is a global problem but only for white persons

Tables:

1. Prevalence rates of cancer per 100,000 among males in Connecticut on January 1, 1982
2. Prevalence rates of cancer per 100,000 among females in Connecticut on January 1, 1982
3. Data and facts on melanoma of the skin

Figures:

1. Wavelengh in nanometers. Electromagnetic spectrum with expanded scale of ultraviolet radiant energy
2. Each black dot indicates site of origin of melanoma of the skin - 731 males and females
3. Melanoma mortality rates in the United States

INTRODUCTION: SUNLIGHT AND HUMANS

Sunlight is both life-sustaining and life destroying for humans. Without sunlight, the surface of the earth would be cold, still and completely lifeless; the sun provides the energy to sustain all life on earth. Yet, humans who are exposed to and receive excessive sunlight can develop fatal melanoma skin cancer and disfiguring non-melanoma skin cancer. Attitudes, customs and lifestyle determine the amount of sun. Moreover, peoples of the world can be divided into black, brown and white. The pigmented peoples of the world (brown and black-skinned persons) are virtually free from the skin-damaging effects of the sun while certain white, non-tanning persons are highly susceptible to the development of melanoma and of non-melanoma skin cancer.

ULTRAVIOLET B (300-320nm) IS THE MOST DAMAGING TO HUMANS

Only a small portion (3 percent) of sunlight is a part of the electromagnetic energy spectrum called ultraviolet which is invisible to the human eye (Fig. 1). Most of the ultraviolet emitted by the sun is absorbed by ozone in the stratosphere and only wavelengths 300-400 nanometers (nm) reach the earth's surface. The ultraviolet B, which includes wavelengths from 300-320 nm is the most damaging to humans affecting the skin (sunburn, skin cancer), eye (cataracts), and the immune system. The EPA recently completed study has been comprehensive and scientifically accurate and Drs.John Hoffman, Terry Yosie and the entire EPA staff should be commended for their assiduous efforts in producing this very large report. The risk estimates and the major types of effects for which quantitative estimates are provided include ozone depletion. additional cases (incidence) and deaths (mortality) related to skin cancer and additional cases of senile cataract. The estimates cover the the United States only. In this statement, I will concentrate on melanoma of the skin and non-melanoma skin cancer.

OZONE DEPLETION → INCREASED UVB INTENSITY → SKIN CANCER

This sequence was first postulated in the early 1970's in relation to proposed supersonic air transport and the effort to ban SST's was led by Senator William Proxmire of Wisconsin. At this time, little was known regarding the epidemiology of skin cancer but it was generally believed that UVB could cause non-melanoma skin cancer, called basal cell carcinomas and squamous cell carcinomas. But UVB was not believed by most to be implicated in the development of the fatal black tumor called malignant melanoma.

Since the 70's there has been a major effort by various groups funded by the United States government to understand the relationship of ozone depletion, increased UVB and human health effects. In the late 70's, there was a surge of interest in ozone depletion related to the increasing use of chlorofluoromethanes which are, as Prof. Rowland says, "so dangerous to the ozone layer". From 1973 to 1984, several multi-disciplinary committees of the National Academy of Sciences (NAS) concentrated on the health effects of UVB increase; a large, heavily funded study was also done by the U.S. Department of Transportation. In all these studies by the various NAS committees and in the present EPA effort, there is no debate regarding the role of ultraviolet radiation in the development of basal cell and squamous cell carcinomas, which is based on the following factors:
(1) latitude dependence (more cases occur in the Sunbelt and in Australia);
(2) the high incidence in a susceptible population: fair-skinned white people (Skin Types I & II) with prolonged occupational or recreational exposure; black people and swarthy whites (Skin Types IV & V) are far less susceptible, and skin cancer of any type is very rare in such people; (3) localization (over 90 percent

on areas most exposed to the sun: head, neck, and dorsa of the hands and forearms); and (4) experimental evidence in mice that wavelengths in the action spectra for the development of squamous cell carcinoma (basal cell carcinoma has not been induced by ultraviolet radiation in animals).

THE PRESENT MELANOMA SKIN CANCER EPIDEMIC WHICH AFFECTS YOUNG AND MIDDLE ADULTS IS NOT DUE TO OZONE DEPLETION

The causative role of ultraviolet radiation in the pathogenesis of malignant melanoma is less firmly established; the action spectrum is not known, because there is no animal model. Furthermore, the principal locations of malignant melanoma are not the areas most exposed to ultraviolet radiation (face and neck) but the relatively less-exposed areas: the upper back in males and females and the lower limbs in females; malignant melanoma is infrequent however in rarely exposed or unespoсed areas (breasts and bathing-suit area of females, bathing trunk area of males). (Fig.2)

The occupational differences in the incidence of both skin carcinoma and malignant melanoma are striking and appear to correspond to patterns of exposure or exposure behavior. Melanoma has the highest incidence in young urban professionals who have a history of short, high-intensity exposure during winter vacations in sunny climates and often a history of painful sunburn. If ultraviolet radiation is a factor in the induction of malignant melanoma, then increased exposure (more leisure time, a shorter work week, charter flights to sunny areas, and so forth) should result in appearance of the tumor at a younger age. Such is the case; 23,000 new cases of malignant melanoma are predicted for 1987. The rate of increase in the incidence of malignant melanoma exceeds that of every other tumor in Canada except lung cancer.

The NAS concluded that UVB is a skin carcinogen and that a reduction of the ozone filter could produce a substantial increase in the incidence of non-melanoma skin cancer. UVB's role as a photocarcinogen for primary melanoma of the skin is still controversial, but is now generally believed to be a contributory factor to the present worldwide "epidemic" of melanoma, with as much as a 340% increase in incidence in the past decade in some areas of the U.S. southwest (Fig.3). Based on the recommendations of the NAS report, the FDA banned the use of fluorocarbons as propellants in aerosol sprays in 1978; however, the use of fluorocarbons (air conditioners, refrigerators, insulation, as a solvent for cleaning electronic circuit boards and as aerosol propellants) has increased markedly since 1978 and will soon more than offset the reductions from the aerosol ban.

The present epidemic of melanoma in whites cannot be attributed to ozone depletion, which has not been significant in the past two decades. Nevertheless, if sunlight and especially UVB are major (if not the only) factors in the development of melanoma of the skin in whites, an increase in UVB as a result of ozone depletion could exacerbate an already major problem. The melanoma mortality rate for the single years from 1978 to 1982 is rising by 3% each year for men and by 1% for women. This is a clear statement that the striking increase in the incidence of melanoma of the skin is not the result of an artifact of "overdiagnosis", as some have conjectured. A large case-control study involving 511 melanoma patients and 511 matched controls has been done by a team of epidemiologists led by Holman in Western Australia. It was established that inability to tan (Skin Types I & II) is an important risk factor for malignant melanoma. Subsequent studies by this same group looked at the complex relation of melanoma of the skin to individual sunlight exposure habits. Increased incidence of superficial spreading melanoma was related to low total outdoor exposure in early adulthood and frequent participation in boating and fishing, frequency of sun-bathing at ages 15-24 years, and exposure of the trunk while working outdoors. Most of the results of this survey support the hypothesis that melanomas other than lentigo maligna melanoma "are related to occasional bursts of recreational sun exposure during a susceptible period in early adult life."

The data from the Connecticut Tumor Registry are as reliable as any in the United States. The Registry is especially valuable because it provides data from 1935 to 1968 - 51 years (47 in the authors' study) of records of newly diagnosed cancers for analysis.

It is surprising to discover that in males aged 30 to 49, melanoma is the second most prevalent cancer (the first being cancer of the testis), and in older males (aged 50 to 59) melanoma is the fourth most prevalent cancer, exceeded only by bladder, colon, and lung cancer (see Table 1). That primary melanoma of the skin is a disease of young and middle-aged men is evident, since melanoma ranks eighth in prevalence in 60 to 69 year old men. Among women, melanoma ranks fourth in the 30 to 49 year old age group, preceeded in order by breast, cervical, and thyroid cancer. In the 50 to 59 year old group, the 60 to 69 year old group, and those older than 70, melanoma prevalence is sixth, ninth, and eleventh, respectively (see Table 2).

A fact sheet for malignant melanoma of the skin is presented in Table 3.

MELANOMA IS ALREADY A PUBLIC HEALTH PROBLEM -- OZONE DEPLETION WOULD WORSEN IT

The recent predictions on the effect of halocarbons point to an increase of UVB by the middle of the next century, even if controls are now put into effect in the United States. A decrease in the average ozone concentration by several percent, which is now predicted, would produce a UVB increase at middle latitudes, leading to several thousand more patients with malignant melanoma, a fatal tumor, and certainly to several hundred thousand more cases of non-melanoma skin cancer. But this is only the tip of the iceberg -- the non-human biologic effects of UVB could have a more catastrophic effect.

MELANOMA IS A GLOBAL PROBLEM BUT ONLY FOR WHITE PERSONS

Senator Proxmire first introduced the hypothesis of ozone depletion from stratospheric pollution at a press conference in the Capital held in March 1971. In the past 16 years, new reliable epidemiologic data has been obtained by exhaustive studies by the various ad hoc committees of the National Academy of Sciences that established a clear relationship between UVB and skin cancer including fatal malignant melanoma. The controversy of ozone depletion has centered in the United States among four groups: scientists, the government, the military and the industrial concerns who manufacture chlorofluorocarbons. In addition, there has been little enthusiasm for global control of chlorofluorocarbons, principally because the 2 billion non-white (pigmented peoples) population are not susceptible to the development of sun-induced melanoma skin cancer. For example, the mortality from melanoma of the skin in whites is: Australia 5.3/100,000, Northern Europe and Scandinavia 3.5/100,000, and North America 2.6/100,000; the mortality in pigmented peoples is less than 0.5/100,000. There is a glimmer of hope for global control of chemicals that are depleting the earth's ozone shield. In what the New York Times called a "rare display of international concern", they reported on May 4, 1987, on negotiations in Geneva at a 31-nation conference sponsored by the United States Environment Program and headed by Dr. Mostafa K. Tolba, there was a tentative agreement to back a freeze of production of chlorofluorocarbons at 1986 levels starting in 1990, and to cut production by 20% within 2 years after that, of the chemicals which scientific evidence indicates are depleting ozone in the upper atmosphere. Dr. Tolba said, "There was no dissent at all about the fact that we are facing a real problem of depletion of the ozone, but because of economic factors, industry needs to have lead time to adjust to changes." The United States' chief negotiator at the Geneva talks, Deputy Assistant Secretary of State Richard E. Benedick, said: "The agreement on ozone is really a landmark because it is the first time the international community is taking hold of an environmental problem before it happens." Heretofore, there has been little display of international will to deal with global environmental threats."

Table 1. Prevalence Rates of Cancer per 100,000 Among Males in Connecticut on January 1, 1982*

Site or Type of Cancer			Age Group			
	0-29	*30-49*	*50-59*	*60-69*	*>70*	*Total***
All	134.4	597.6	2,296.3	5,380.3	11,809.7	1,789.0
Buccal cavity/pharynx	2.6	32.6	196.5	390.2	608.3	107.7
Stomach	0.3	8.0	37.9	102.0	230.6	32.2
Colon	0.7	26.2	246.4	723.8	2,053.2	249.3
Rectum	0.3	13.4	161.1	477.3	1,123.2	144.7
Larynx	0.0	16.4	136.4	332.9	475.4	81.4
Lung	0.8	27.7	238.6	564.5	757.6	134.8
Melanoma (skin)	**5.6**	**74.5**	**200.7**	**238.3**	**261.3**	**80.6**
Prostate	0.1	2.6	129.2	906.3	3,696.8	372.3
Testis	19.1	95.3	101.6	93.8	42.8	53.6
Bladder	2.2	43.2	319.1	729.0	1,679.9	232.6
Kidney	6.6	21.1	101.6	208.5	332.7	60.8
Hodgkin's disease	25.3	70.7	40.9	35.0	29.6	38.7
Non-Hodgkin's lymphoma	8.9	37.3	126.2	198.1	261.3	62.2
Leukemia	16.5	13.4	40.3	114.7	203.1	40.6

*Only cancers with prevalence rates greater than 60: 100,000 are included

**Age-adjusted to the 1980 U.S. population

(Modified from Feldman AR et al: N Engl J Med 315: 1394, 1986)

Table 2. Prevalence Rates of Cancer per 100,000 Among Females in Connecticut on January 1, 1982*

Site or Type of Cancer			Age Group			
	0-29	*30-49*	*50-59*	*60-69*	*>70*	*Total***
All	142.7	1,169.8	4,538.0	7,530.7	10,635.0	2,221.6
Buccal cavity/pharynx	2.8	24.1	96.3	165.1	198.8	45.5
Stomach	0.1	4.6	17.2	57.3	139.9	17.8
Colon	1.7	31.8	251.2	662.8	1,887.7	224.1
Rectum	0.1	14.1	124.0	350.3	722.9	97.6
Lung	0.3	24.5	143.3	272.2	233.6	61.2
Melanoma (skin)	**9.5**	**102.5**	**184.3**	**188.4**	**183.6**	**77.0**
Breast	4.2	413.3	2,067.3	2,983.4	3,888.7	847.6
Cervix uteri	8.1	120.8	286.6	447.4	528.0	138.4
Corpus uteri	0.7	58.3	542.8	1,234.9	1,342.0	273.0
Ovary	8.5	62.4	227.4	312.5	329.2	92.7
Bladder	1.3	22.1	101.3	201.0	410.8	62.5
Kidney	8.7	11.9	45.9	94.5	158.3	31.4
Thyroid	14.6	112.7	146.6	129.2	107.0	67.7
Non-Hodgkin's lymphoma	5.2	27.5	100.7	172.0	210.2	49.3
Leukemia	13.4	10.0	27.1	65.5	129.8	26.9

*Only cancers with prevalence rates greater than 60: 100,000 are included.

**Age-adjusted to the 1980 U.S. population

(Modified from Feldman AR et al: N Engl J Med 315: 1394, 1986)

TABLE 3: DATA AND FACTS ON MALIGNANT MELANOMA OF SKIN

1. Melanoma represents 2% of all cancers by incidence (excluding non-melanoma skin cancers). The lifetime risk for development of melanoma of the skin white people has increased by 1000 since the 1930's. At the present, in 1987, 1:150 white persons in the United States will develop melanoma of the skin. By 1990, it is predicted that 1:100 persons will develop melanoma. Melanoma is increasing in the United States by 3% per year. White persons are affected 10 times more than brown or black persons.
2. Incidence is latitude dependent; crude incidence rates (whites), 1980-82 per 100,000 population per year:

Northern United States (Connecticut)	9
Southern United States (Arizona)	26

The number of melanomas and non-melanoma skin cancers doubles every 8 degrees of latitude nearer the equator. The highest mortality in the United States is in the Sunbelt states (Fig.3).

3. Total new cancer cases estimated in the United States for 1987:

Malignant melanoma	23,000
Primary brain tumor	13,700
Thyroid	10,600
Multiple myeloma	9,600
Pharynx	8,800
Hodgkin's disease	6,900

4. Incidence of melanoma is increasing: Connecticut Registry, per 100,000 population per year:

1935 - 1939	1.2
1965 - 1969	4.8
1976 - 1977	7.2
1980 - 1981	9.0

5. Overall deaths (United States, 6000) melanoma represents 1 to 2% of all cancer deaths.
6. Five-year survival of clinical Stage I tumors based on primary tumor thickness:

<0.85	99%
0.85 - 1.69	94%
1.70 - 3.64	78%
≥3.65	42%

7. Most frequent sites in whites:
   Male: back, anterior torso, upper extremity, head and neck
   Female: back, lower leg, upper extremity, head and neck
8. Most frequent sites in blacks and Orientals:
   soles, mucous membranes, palms, nail beds

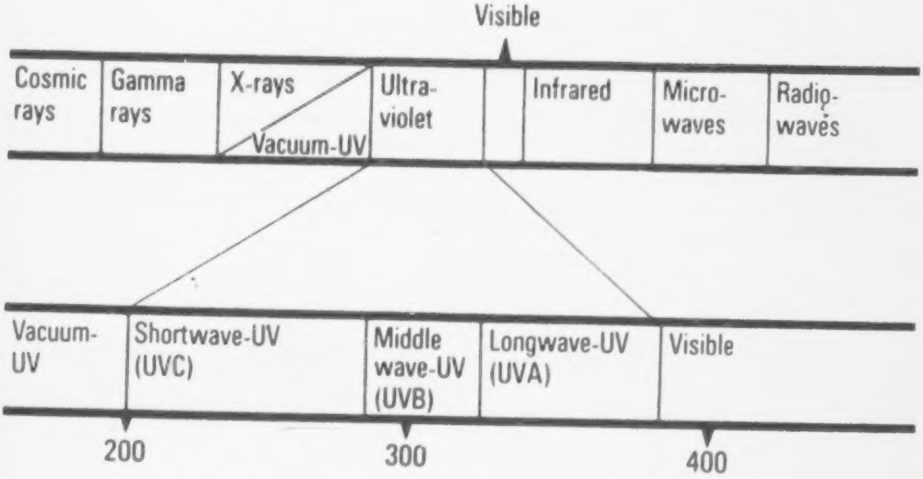
Visible
Cosmic rays
Gamma rays
X-rays
Vacuum-UV
Ultra-violet
Infrared
Micro-waves
Radio-waves
Vacuum-UV
Shortwave-UV (UVC)
Middle wave-UV (UVB)
Longwave-UV (UVA)
Visible
200
300
400

Figure 1. WAVELENGTH IN NANOMETERS. ELECTROMAGNETIC SPECTRUM WITH EXPANDED SCALE OF ULTRAVIOLET RADIANT ENERGY

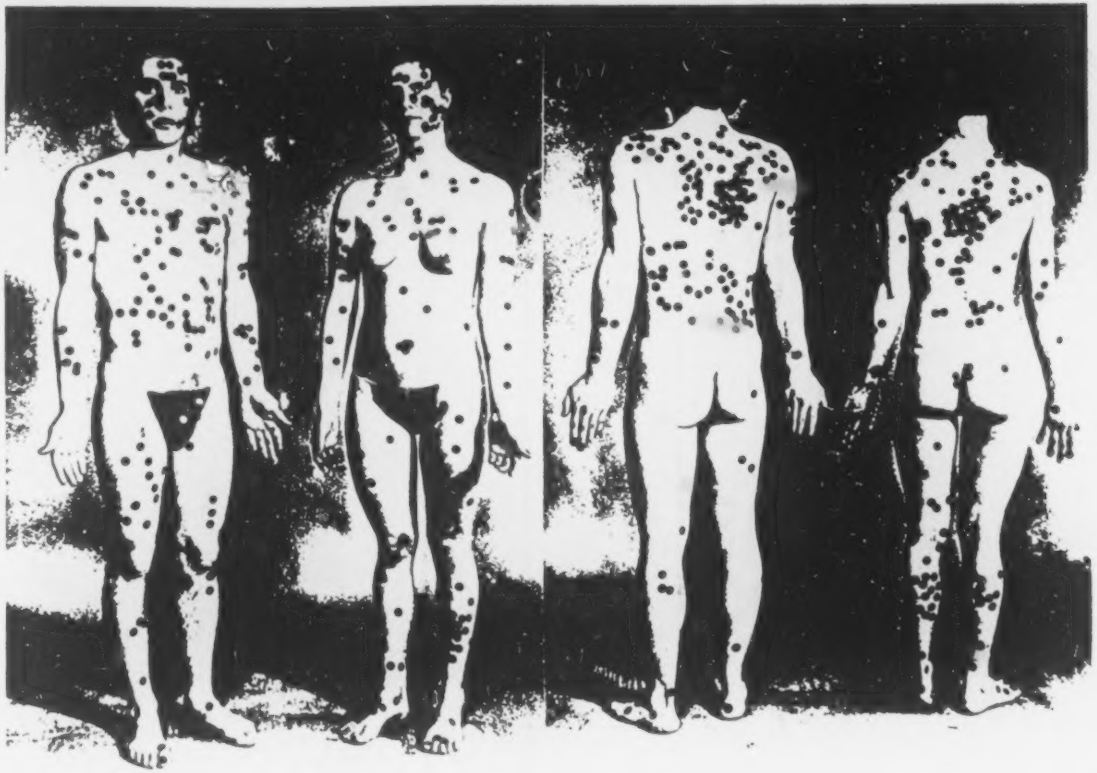

FIGURE 2. EACH BLACK DOT INDICATES SITE OF ORIGIN OF MELANOMA OF THE SKIN - 731 MALES and FEMALES

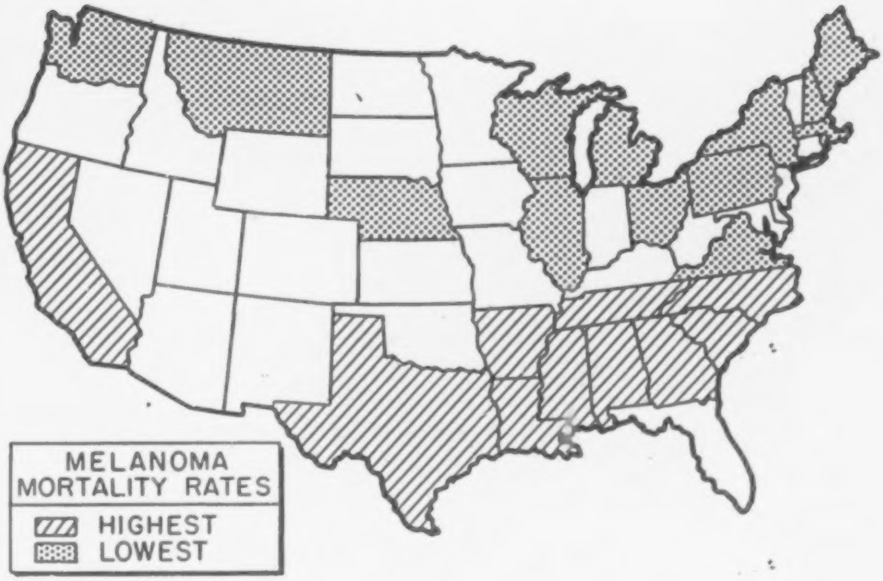
MELANOMA
MORTALITY RATES
▨ HIGHEST
▦ LOWEST

Figure 3. States with the highest and lowest mortality from melanoma in the United States (1950-1969). The predominance of melanoma in the south is consistent with increased exposure to solar ultraviolet radiation, but other factors probably play a role as well. (Adapted from Fraumeni JF: The face of cancer in the United States. Hosp.Pract., p.81, December 1983)

EFFECTS OF SUNLIGHT ON THE EYE

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TABLE OF CONTENTS

I. INTRODUCTION

II. DIRECT RADIATION EFFECTS ON OCULAR TISSUES

- A. Cornea
- B. Lens
    - 1. Intrinsic Fluorescence of the Lens
    - 2. Extrinsic Fluorescence of the Lens
    - 3. Mechanisms in Optical Radiation Cataractogenesis
    - 4. Defense Mechanisms of the Lens
        - a. Photo-oxidative Damage
        - b. Singlet Oxygen
- C. Vitreous
- D. Retina
    - 1. Photochemical Damage
    - 2. Recovery From Visible Light Damage
    - 3. Body Temperature and Light Damage
    - 4. Ophthalmoscopy, the Operating Microscope and Retinal Damage
    - 5. Summary and Conclusions

III. PHOTOSENSITIZED RADIATION EFFECTS ON OCULAR TISSUES

IV. CLINICAL LENS FLUORESCENCE STUDIES

V. THE ROLE OF COMMERCIAL SUNGLASSES

VI. VDT'S AND THE EYE

VII. POTENTIAL HAZARDS FROM OZONE DEPLETION

VIII. THERAPY

- A. Radiation Filters
- B. Medication

INTRODUCTION

The sun is the natural source for most of the electromagnetic radiation in our atmosphere. Depending on geographic location, we are constantly exposed to the non-ionizing portion of the electromagnetic spectrum [mainly in the ultraviolet (UV), visible, and infrared (IR) regions] at much higher intensities compared with background ionizing radiation. Fortunately, the ozone, oxygen, water, and carbon dioxide molecules in our atmosphere filter out a significant portion of the more lethal wavelengths of such solar radiation [i.e., the shortwave UV (10-280 nm) rays].

It is estimated that approximately 8 percent (11 mW/cm^2) of solar radiation above the atmosphere is in the 280-400 nm ultraviolet region. At sea level this is decreased to 2-5 m/W/cm^2, depending on geographic location and season.[1] Aside from solar radiation, man-made ultraviolet radiation also plays a role in ocular photoxicity; a relatively small one in the phakic individual and a more significant one in the aphakic or pseudophakic eye. The spectral output of our most common fluorescent lamps is relatively low at these wavelengths and should not pose a problem except in patients who are being treated with photosensitizing drugs and in aphakes and pseudophakes. However, exposure to photo flood lamps or the black light lamps frequently used in various laboratories might present a potential hazard since their output can approach approximately 5 to 10 percent of the average levels of solar radiation in our atmosphere.[1] Furthermore, a much more significant hazard exists in industries which utilize UV radiation in certain polymerization reactions. Recent studies have also demonstrated that UV and short wavelength visible radiation exposure from indirect ophthalmoscopy and the operating microscope can also induce photochemical damage in the retina.[2-6]

The eye is the only organ or tissue in the body (aside from the skin) that is particularly sensitive to the non-ionizing wavelengths of optical radiation (280 nm to 1400 nm) normally present in our environment. In addition to infrared and visible radiation we are constatnly exposed to ultraviolet radiation (solar and man-made) throughout life.

Since the normal cornea, aqueous, ocular lens and vitreous are almost completely transparent to all but the shorter wavelengths of visible light (although the aging lens does absorb increasing amounts of shortwave visible radiation[1,7]), one would not anticipate photic damage to these tissues from visible radiation. Only the retina is susceptible to photodamage from visible radiation. Furthermore, in order for non-ionizing radiation to exert an effect, it must be absorbed. While the retina contains chromophores whose function it is to absorb visible radiation (the photoreceptor rods and cones and the macular pigment), the other ocular tissues anterior to the retina, have very few chromophores which can absorb such wavelengths. Nature has provided us with transparent ocular media which are avascular and contain very few visible wavelength absorbing chromophores, in order to effectively transmit (as well as refract) the specific wavelengths required to initiate the visual process by photochemical reactions. However, these tissues do have the ability to absorb varying amounts of ultraviolet radiation (particularly the ocular lens.) The shorter the wavelengths of radiation absorbed, the greater the potential for photic damage since there is an inverse relationship between a wavelength and the photon energy associated with it (Figure 1). Thus, UV radiation is the non-ionizing portion of the electromagnetic spectrum which could cause the most ocular damage, provided that it is absorbed. As we shall see, this applies to all the ocular tissues including the retina in the very young eye (where the lens has not as yet become an effective UV filter), but in particular, the ocular lens sustains the greatest amount of photochemical change during a lifetime of exposure to ambient UV radiation.

Infrared radiation (750nm->1M) has a much lower photon energy than visible or UV radiation (Fig. 1) and exerts it action by increasing the motion of molecules: i.e., a heating effect. Under normal circumstances, ambient infrared radiation is by itself incapable of exerting damage to ocular tissues. Although it is absorbed by water (hence by most biologic tissues), the amount of IR radiation we are normally exposed to is insufficient to cause any significant heating. Obviously very high exposure levels (e.g., CO_2 laser or Nd:YAG laser) can exert significant damage due to acoustic gradients as well as intense heating.[8,9] Blast furnances can also cause IR cataracts (Glass Blower's Cataract). However, normal daily life does not expose us to such levels of radiation, and the only effects of IR radiation at ambient levels are those associated with small temperature elevations (1-3 C degrees) in the absorbing tissues (mainly the lens and retina) which could exert an effect by enhancing UV induced photochemical changes.

Ultraviolet induced changes in human and animal ocular tissues can be attributed to two mechanisms: a direct or intrinsic process in which the radiation is absorbed by specific naturally occurrring chromophores within these tissues (e.g., the nucleic acids or aromatic amino acid residues), and an indirect or photosensitized process in which the radiation is initially absorbed by photosensitizing drugs or other extrinsic compounds.

DIRECT RADIATION EFFECTS ON OCULAR TISSUES

Radiation must be absorbed in order to cause a change in the molecule since absorbed energy is required to promote a chemical change. Molecules in excited electronic states have different chemical and physical properties than their counterparts in the ground state (prior to absorption of energy). Thus cells that do not contain chemical compounds absorbing at certain wavelengths will tend to transmit these wavelengths. For example, the nucleic acids and many proteins in a cell are essentially transparent to and transmit visible light but absorb certain wavelenghts in the UV region (between 250 and 295 nm) and can be damaged by this form of radiation. The absorption of visible radiation gives the molecule its specific color (and characteristic absorption spectrum). Thus rhodopsin (the visual pigment in the rod receptor cell of the retina) has a red color since it absorbs maximally in the blue green portion of the visible spectrum and transmits or reflects all red light (above 600 nm). Hemoglobin has absorption peaks in the UV and visible region (275, 400, and 540 to 576 nm) which endows it with its characteristic color. These macromolecules can be damaged by visible radiation at their specific absorption wavelengths as well as by UV radiation. The recent therapeutic application involving phototherapy for certain types of malignancy makes use of these principles. Haematoporphyrin derivatives (HPD) are infused into a tumor and their absorption characteristics (in the red portion of the visible spectrum) enable one to destroy the malignancy with red light.[10] Attempts are currently underway to treat intraocular tumors in this manner.[11]

Since the effect of non-ionizing radiation on a cell depends on the specific chemical composition within the cell, that is on the presence of absorbing molecules (chromophores), a knowledge of the chemical composition as well as the morphology of the eye can be helpful in predicting the potential for photochemical damage occurring in specific ocular tissues during a lifetime of exposure to ambient optical radiation.

CORNEA

The cornea and lens have similar optical functions. They must be transparent to visible light and capable of refracting the central core of incoming light so that it focuses properly on the appropriate region of the retina (macula) for normal visual acuity. The cornea is the major optical system in the eye, and its optical properties are determined by its refractive index, transparency to visible light (and UV radiation above 295 nm), and by its radius of curvature. The radius of curvature is determined by the growth and development of the normal cornea; the refractive index is determined by its chemical composition; the transparency of the cornea is determined by its avascularity as well as it morphology and chemical composition. Although it is a relatively thin membrane, ranging from 0.5 to 0.57 mm in the center to about 0.66 to 0.67 mm at the periphery,[1] the cornea has a considerable amount of inherent tensile strength. This strength is due to the presence and arrangement of the collagen fibrils making up the lamellae within the corneal stroma. The collagen fibrils within the stromal lamellae run parallel to one another. Adjacent lamellae consist of fibrils lying parallel to but at right angles to one another, thereby forming a lattice network that is not interwoven. The fibrils and the lamellae are held together by a cement substance composed of a complex of mucopolysaccharides and proteins. Aside from endowing it with tensile strength, the geometric arrangement of the collagen fibrils (in an unwoven lattice pattern) plays a significant role in corneal transparency. The perfect lattice periodicity of these fibrils would result in zero intensity of scattered light in all directions - hence, transparency to visible light.[12] Benedek, however, has noted that perfect lattice periodicity is not present in the cornea, but it is still transparent to visible light since the density of light-scattering particles is the same throughout this tissue.[13,14] Thus, the total intensity of scattered light will be zero; that is, the medium (cornea) is perfectly transparent if the density of scattered particles is uniform throughout. Corneal transparency is extremely sensitive to its state of hydration (about 75% of the cornea is composed of water). Even a small increase in the water content of the cornea will result in some loss of transparency. The metabolic activity of the cornea maintains the tissue in its proper state of deturgescence. The epithelium and endothelium play a major role in the metabolic maintenance of corneal transparency exerting their influence by an active as well as a passive process.[1] The relative importance of these two layers in the cornea is often reflected in clinical practice. It is well known that trauma to the endothelial surface during surgery will result in more severe and prolonged corneal edema than will damage to the epithelial surface.

It should also be noted that both optical systems of the eye are completely avascular. The peripheral cornea (limbal portion) receives its major nourishment from the perilimbal vessels present in the episclera and conjunctiva while the lens is a completely avascular tissue and cannot receive any nourishment directly from the blood stream. The aqueous humor provides a significant amount of nourishment to the cornea, particularly to the inner layers, and completely nourishes the lens. The tear film is a third source of nourishment for the cornea. The corneal epithelium can obtain oxygen from the atmosphere, while the endothelium obtains its oxygen supply from the underlying aqueous humor. In contrast, the ocular lens can obtain oxygen only from the relatively low concentration present in the aqueous humor.[1] Thus the metabolic activity in the corneal epithelium and particularly its reparative processes are much more active than those in the lens epithelial cells and this can play a significant role in determining the degree of UV radiation damage to these tissues.

Aside from its morphology which permits transparency of visible light, the chemical composition of the cornea provides further clues as to which wavelengths of radiation will be absorbed or transmitted. The cornea is made up of water (75%), protein (approximately 20%), polysaccharides (approximately 4% of the dry weight, or 1% of the wet weight), lipids and nucleic acids. Aside from the small amount of the cytochromes that constitute the respiratory enzymes (responsible for oxidative phosphorylation), over 99% of the chemical composition of the cornea is composed of molecules that contain chromophores absorbing only in the UV region between 200 and 295 nm. The water and carbohydrate (polysaccharide) molecules will absorb UV radiation below 230 to 235 nm, the nucleic acids will absorb at approximately 250 to 260 nm, and the protein portion of the cornea will absorb in the 235-to-250 nm (for aliphatic amino acids) and in the 270-to-295 nm region (mainly due to the aromatic amino acids, phenylalanine, tyrosine, and tryptophan). The sugars comprising the corneal polysaccharides only absorb UV radiation below 250 nm. The ground substance of the corneal stroma is made up of a complex of mucopolysaccharides and protein. The protein portion of the ground substance of the cornea is responsible for absorption of UV radiation in the 275-to-295 nm region. The major portion of the corneal protein is composed of collagen (which comprises about two-thirds of the total). Collagen has a relatively low absorbtion at 280 nm due to its low content of the three aromatic amino acid residues mainly responsible for the 280 nm absorption spectra of most proteins.

The foregoing discussion on the morphology and composition of the cornea has demonstrated that this tissue should be transparent to and transmit all visible light (400 to 750 nm) and most of the ultraviolet radiation longer than 295 nm. This is borne out by data from several laboratories.[1] There is a sudden and marked decrease in the absorption spectra of human corneal tissue at approximately 295 nm. A corresponding increase in corneal transmission occurs above 295 nm, with this tissue transmitting over 90 percent of light above 400 nm in the young individual. The percent transmission of visible light decreases with age, as does the transmission of UV radiation between 300 and 400 nm (Fig. 2) The latter decrease can be accounted for by the generation of a small amount of fluorescent chromophores as the cornea ages.[15,16] These photochemically derived pigments play an insignificant role in the cornea but assume much greater importance in the ocular lens.[1,15,16] It is true that other light-absorbing chromophores, such as the cytochromes, are present in both cornea (epitheliuim and endothelium) and lens (epithelium), but they represent a very minute proportion compared with the aforementioned chromophores and can be disregarded with respect to their potential effect on the UV and visible absorption and transmission characteristics of these two tissues.

From the foregoing discussion one can predict an UV action spectrum for corneal damage having at least two peaks; one at approximately 260 nm and the second at 280 to 295 nm. Such an action spectrum has been reported by various investigators.[17-19] These investigators noted that the maximum efficiency for experimental photokeratitis and photokeratoconjunctivitis peaks sharply at 288 to 290 nm, with a smaller peak at 254 nm. This effect can be ascribed to absorption by the nucleotides (at 254 nm) and by tryrosine and tryptophan in the corneal epithelium. Studies on free radical generation in human corneas exposed to 290 nm radiation show an interesting correlation with the UV action spectrum for photokeratitis reported by Sherashov[19] as shown in Figure 3. Clinically, corneal photodamage from ultraviolet radiation has long been appreciated, a typical example being snow blindness experienced by polar explorers. This type of photokeratitis is due to the relatively high levels of ultraviolet radiation which can be reflected by snow compared with less than 5% from earth or grass. Aside from the well known polar and industrial photokeratitis, ultraviolet radiation has also been implicated in a variety of conjunctiveal and corneal lesions. These include pingueculae and pterygiums, exposure keratosis (which involves epithelial changes related to actinic radiation and is analogous to actinic keratosis of the skin), nodular band shaped keratopathy, experimentally induced tumors in animals, and the relatively rare dysplasia and intra-epithelial carcinoma. Certain corneal diseases can also be triggered by exposure to ultraviolet radiation; for example, Herpes Simplex Keratitis and Recurrent Erosions of the cornea.

Since the cornea filters out UV radiation shorter than 295 nm, we are left with the question regarding the effect of longer wavelength UV radiation (300-400 nm) on the eye. The cornea transmits almost all of this radiation into the interior of the globe and the same can be said for the aqueous humor. The ocular lens absorbs a significantly increasing amount of this radiation, as well as visible light, as it ages.

LENS

A knowledge of the morphology and composition of the lens will not only explain its transparency to visible light but will also indicate why this organ is suscepitable to UV induced photochemical changes as it ages.

The human crystalline lens, derived from the surface ectoderm at about the 4.5 mm stage of embryonic life, is a unique, biconvex, transparent, and avascular organ that represents a pure cell line and preserves the complete population of cells from fetal life until death. The mature strap-like lens fiber cells lose their nuclei but remain viable with only scanty organelles.

The lens fibers grow from all around the equatorial region and meet at radiating lines or sutures. During the first eight weeks of life, the lens is a sphere. Since further growth of the lens depends on the continuous division of cells located in the germinative zone, there will be a gradual increase in the equatorial diameter of the lens in comparison with its axial diameter, and the organ will take on the more characteristic oval shape seen in the adult.

The adult human lens is a precisely formed structure containing about 65% water and 35% organic matter, the latter being chiefly structural proteins. Since the structural proteins (alpha, beta, and gamma crystallins and the insoluble protein fraction) constitute most of the dry weight of the lens, they must play a major role in the transmission as well as in the absorption and refraction of light through this organ. The degree of hydration and perhaps the action of the mucopolysaccharides as cement substances between the lens fibers may also play a role in lenticular transparency. In the infant, this organ does not contain any chromophores capable of absorbing a significant amount of visible radiation (400 to 750 nm), and the potential for absorbing UV radiation longer than 295 nm resides mainly in the tryptophan residues present in the lens proteins (and the relatively small amount of free tryptophan within the lens amino acid pool). Aside from the minute amount of cytochromes in the lens epithelial cells, there are no other chromophores in the young lens capable of absorbing radiation wavelengths longer than 320 nm. The metabolic activity of the lens is mainly directed toward maintaining normal hydration (60-65%) and protein synthesis. The constituent lens proteins are densely packed and arranged in a high degree of spatial order within the intact fiber. There is little change in the density of scattering particles as one moves from point to point within the lens. According to Benedek[13,14] the changes in the index of refraction within specific anatomic zones of the lens still permit transparency. That is, "the scattered waves add up to give zero intensity in all directions except for those directions predicted for the bending of the primary beam by the laws of refraction in geometrical optics".[14] Refraction itself, therefore is a consequence of scattering and the refracted beam is the result of constructive interference of the scattered light. As Benedek has pointed out[13] "when lens proteins are extracted and mixed with water the constituent proteins are now dispersed throughout the solution. The proteins are no longer tightly packed and the density of proteins fluctuates markedly about its average value, hence, the solution can appear milky or turbid." In a simplified analogy, the accumulaltion of water within the lens results in a decrease of transparency. Localized alterations in the density of packing of lens proteins, because of aggregation and/or configurational changes developing in various portions of the lens, will lead to changes in transparency; that is, the development of opacities which could be due to localized changes in the refractive index.

Aging of the lens is reflected by pronounced changes at the molecular level, particularly with respect to the structural lens proteins, which constitute most of its dry weight. It seems that post-synthetic modifications are mainly involved, although errors at the translational level cannot be excluded. A variety of chemically or physically defined processes have been observed in lens proteins with aging. At birth, >95% of the human structural lens proteins are water soluble. One well defined aging parameter is the progressive age related increase in the amount of insoluble protein (to 40% or more of the total crystallin content), with a concomittant decrease in the total soluble protein (TSP) fraction.[1] The generation of a high molecular weight fraction (HMW) has been implicated in the increase in light scattering which develops as the lens ages.[20] There is also a marked change in the relative concentration of at least one of the soluble crystallin fractions. At birth, the gamma crystallins constitute over 50% of the TSP and then decrease progressively with age to c.a. 10% in the old human lens (60+ age group) and in the two year old rat lens.[1] The aggregation/insolubilization processes occurring with age appear to be associated with the formation of disulfide bridges and other covalent crosslinks. The latter may (at least in part) be due to chronic cummulative exposure to ambient UV radiation (over a 30-50 year span) resulting in the photochemical generation of a series of progressively longer wavelength UV and visible radiation absorbing chromophores in the lens.[1,15,16,21] Thus as the lens ages it displays an increasing absorbance in the 300-400 nm UV region, and in the visible region, which is associated with increased pigmentation of the lens core (nucleus). This is associated with increased lenticular fluorescence.

Intrinsic Fluorescence of The Lens

Before discussing the visible fluorescence of the lens, it is important to note that most proteins are endowed with an intrinsic UV excited fluorescence because they contain aromatic amino acids (phenylalanine, tyrosine and tryptophan). Of these three aromatic amino acids, phenylalanine has the lowest fluorescence quantum yield (approximately 1/10 to 1/20 of the latter two). Protein fluorescence spectra are thus generally considered only with respect to tyrosine and tryptophan. The presence of even one tryptophan residue in a protein (for example, horse serum albumin which has 17 tyrosines and 1 tryptophan) will result in an intrinsic fluorescence essentially that of tryptophan alone. Thus in most proteins containing at least one tryptophan residue, tyrosine appears to have a very low quantum efficiency so that the emission from this residue is markedly overshadowed by tryuptophan fluorescence. However, tryptophan fluorescence in proteins appears to have quantum yields which in some cases are equivalent to the free amino acid.[22] It is also known that the tryptophan fluorescence maximum in proteins varies from 330 to 352 nm depending on the location of this amino acid within the protein, whereas free tryptophan has a characteristic fluorescence emission maximum at approximately 350 nm. It should be noted that tryptophan residues in native proteins are not necessarily present in identical locations nor are they equally influenced by their environment.[23,24]

The microenvironment of every residue is characterized by a particular set of physicochemical conditions such as: polarizability, microviscosity, availability of charged groups, and possible specific interactions, that can influence chromophore fluorescence. Thus, protein (tryptophan) fluorescence is conditioned by the sum of fluorescent contributions of individual tryptophan residues which can vary over a relatively wide range. Studies using spectral band width, spectral maximum position, fluorescence quenching by external ionic quenchers, fluorescence lifetime, quantum yield and changes upon denaturation, on a variety of proteins, indicate that fluorescence properties of various tryptophan residues in proteins can be delineated into three discrete spectral classes.[23,24] The Type I tryptophan residues are buried in nonpolar regions of the protein, and the Type II and III tryptophan residues are located on the protein surface, Type III being fully exposed to water and Type II in limited contact with water. In the following discussion, we will describe how these ideas can be applied to tryptophan fluorescence in lens proteins.

Lens proteins, in general have a considerably higher content of tyrosine than tryptophan residues, but the presence of the latter results in an intrinsic protein fluorescence in the lens due to tryptophan alone.[21] The data show that the tryptophan fluorescence maximum in whole lenses is at 332 ± 2 nm with a band width of 47 nm. These results indicate that the majority of tryptophan residues in mammalian lenses belong to Type I of the Burstein classification,[23] i.e. they are buried in nonpolar regions of the proteins.

Fluorescence lifetime measurements on intact lenses support the conclusions that lens protein tryptophan residues belong to Type I. Analysis of the decay data produces a fluorescence lifetime of 2.3 nsec, compared to a value of 2.8 nsec which is obtained for free tryptophan in aqueous solution. The value for tryptophan in the lens is consistent with these residues being located primarily in hydrophobic environments. Recent studies on bovine and human lens protein provide further substantiation that the tryptophan residues in the gamma crystallins are all buried or in crevice positions.[25-27] In the alpha and beta crystallins, most of the tryptophan residues are likewise buried, although one of the beta fractions may contain several surface tryptophans.

EXTRINSIC FLUORESCENCE OF THE LENS

The visible fluorescense of the ocular lens was fist noted well over 100 years ago,[28] but it was not until the last decade that this phenomenon was associated with increased yellow coloration of the lens nucleus by the increased visible and near UV absorption. Francois et al.[29] noted the presence of a fluorescent peptide in primate lenses which could be activated by UV light. Specific fluorescent proteins in the human and other mammalian lenses have been demonstrated by a variety of investigators.[15,16,30-42] In addition to the fluorescence due to tryptophan these proteins contain one or more fluorescent chromophores (fluorogens) with activation wavelengths of approximately 340-360 nm and 420-435 and emission maxima at 420-440 nm and 500-520 nm.[21] This type of fluorescence has been shown to be present in the soluble, high molecular weight (HMW) and insoluble fractions of the human lens (mainly in the latter) and to increase with age, particularly in the insoluble protein fraction. These fluorogens are tightly bound to peptides derived from the insoluble lens protein.

In vitro UV-induced changes in human lenses include increased visible fluorescence intensities at 440 nm and 520 nm and increased pigmentation.[1,15,16] Similar fluorescence enhancement can be observed in UV-irradiated animal lenses both in vitro and in vivo.[1,15,43] These studies indicate that the photochemical changes are similar to the increasing fluorescence seen in normal human lenses as they age.[1,15,16,21] The cumulative effects of chronic exposure to ambient UV radiation include the generation of a series of fluorescent chromophores (absorbing at increasingly longer wavelengths), a deepening yellow color of the lens nucleus, and a progressive increase in the level of insoluble lens proteins. The latter phenomenon may be related to the cross-linking of previously soluble polypeptides by some of the fluorescent pigments as well as by disulfide bond formation.

Since the human ocular lens is constantly exposed to ambient UV radiation (300 to 400 nm) throughout life, the consequence of cumulative photochemical damage is an increasing absorption of UV radiation and some visible light due to the presence of photochemically generated fluorescent chromophores which increase in concentration and in number as the lens ages. UV and visible light transmission studies on normal human lenses ranging in age from 3 days to 82 years have shown that over 75% of the UV radiation (300 to 400 nm) is transmitted by lenses under 10 years of age, while the corresponding UV transmission in lenses above 25 years of age drops markedly (Fig. 4). These data are consistent with the relative lack of UV absorbing chromophores in the young lens and an increase in their concentration as the lens ages.[1] Accompanying the measured increase in these chromophores and decrease in light transmission, there is a concomitant increase in the yellow color of the lens nucleus as it ages. These pigments are mainly confined to the nucleus and may play a role in the development of nuclear sclerosis. However, nuclear sclerosis can also develop without significant discoloration. The discoloration is mainly confined to the lens nucleus since the cortex has much higher levels of glutathione and other compounds capable of aborting most of the photochemical reactions.[1,15,16] In about 10% of our population, this process progresses at a more rapid pace resulting in the development of the brown (nuclear) cataract which is an extreme examples of these age related photochemical changes. This type of discoloration, in moderation, is actually beneficial since it enables the lens to become a very effective filter for UV and shortwavelength visible radiation (by the second to third decade) thus protecting the retina from cumulative photochemical damage which could occur during our lifetime. Recent studies have shown that such radiation can cause irreversible retinal photodamage in the aphakic Rhesus monkey and even in man.[2-6,44-47] It is interesting that nature has provided us with the ability to develop a lenticular UV filter to protect the retina from continous radiation exposure which could be harmful, particularly in the older individual where the retinal metabolism and repair processes are no longer as effective as in the young. We are now beginning to see confirmation of the hypothesis that long wavelength UV radiation may play a role in certain retinal diseases (e.g., cystoid macular edema) which tend to occur in older patients following removal of their cataractous lenses and even in degenerative processes (macular degeneration and retinitis pigmentosa).

Although only a small amount of UV radiation from the sun enters the eye under normal circumstances, the cumulative effect of many years exposure is significant, particularly when one considers man's ever increasing life span. Epidemiologic surveys provide some support for the thesis that sunlight plays a role in lenticular aging and in the generation of senile cataracts.[48-51] For example, cataracts and the rate of cataract extraction are much higher in India, Pakistan, and certain areas of Africa than in the temperate zones. An epidemiologic investigation into the relationship between sunlight and cataract in the United States reported that ". . . cataract to control ratios for persons aged 65 years or older were significantly larger in locations with large amounts of sunlight . . .".[48]

Two recent epidemiologic studies involving Australian aborigines exposed to relatively intense solar radiation are of interest. Detailed personal histories were obtained on 350 individuals, and the possible role of a variety of environmental factors in cataractogenesis were investigated. Of the 350 individuals studied by Taylor,[49] all of whom were over 30 years of age, 116 had lens opacities as determined by slit-lamp examination. These findings indicate a relationship between cataracts, increased hours of sunlight, and higher annual UV radiation levels. Aside from age, no other factors studied appeared to be associated with cataractogenesis. Hollows and Moran's study,[50] involving a much greater geographical area and over 50% of the total Aborigine population, found a statistically significant correlation between environmental UV irradiation and the prevalence of cataract. Cataracts occurred much more frequently in the younger age group (40-59 yrs) in zones with high UV radiation than in zones with low UV irradiation. Brilliant et al.[51] studied the relationship between the prevalence of cataracts, altitude and hours of sunlight exposure in Nepal. Exposure to an average of 12 hours of sunlight resulted in 3.8 times the number of cataracts compared with individuals exposed to 7 hours of less of sunlight. These epidemiologic studies support the hypothesis that senile cataracts are associated with higher exposure to sunlight. Obviously other factors play a role in cataractogenesis including heredity, nutrition, metablosim, etc.

Aside from the effects of chronic exposure to ambient UV radiation, exposure to higher radiation levels can produce cortical opacities in human, rat, and rabbit lenses _in vitro_ and _in vivo_.[52-54] Thus more intense UV radiation (300 nm and longer) can induce lens changes involving the cortex while chronic exposure mainly affects the lens nucleus. These effects appear to be dose and time related.[55] There is also the possibility that more intense UV radiation may affect the protein/water order within the lens resulting in the formation of "water lakes" associated with protein aggregates. This would give rise to localized areas of marked changes in refractive index in the injured site resulting in light scattering and opacification. Studies on rabbit lenses exposed to 337 nm laser irradiation demonstrate marked changes in their water component.[56] These wavelengths have sufficient photon energies (1-1.5 eV) to disrupt the protein/water order in the lens and give rise to sudden changes in refractive index resulting in localized opacities.

MECHANISMS IN OPTICAL RADIATION CATARACTOGENESIS

In the ocular lens, free radicals have been implicated as participating in a number of the processes associated with aging and cataractogenesis.[15,57,58] Free radicals (i.e., species with unpaired electron spin) can be produced in biosystems in a variety of ways. Once generated, the radicals are capable of initiating and engaging in a variety of reactions, many of which, if uncontrolled, are detrimental to the function of both the molecular species in which the radical is generated and those species with which the radical interacts. Among the detrimental phenomena that have been related to free radical generation are enzyme inactivation, membrane damage via lipid peroxidation, protein crosslinking and aggregation, and deoxyribonucleic acid alteration. With respect to the ocular lens, a free radical mechanism may be responsible for the observed increase in fluorescent chromophores that occurs with aging.[1,16] When lenticular levels of glutathione, a free radical scavenger, are reduced by the addition of 3-aminotriazole to the incubation medium, the ultraviolet-induced development of non-tryptophan fluorescent chromophores in whole lens incubation experiments is enhanced.[15,43] Conversely, when D-penicillamine, another free radical scavenger, is included in the medium, ultraviolet-induced fluorescent chromophore production is almost completely suppressed.[15,58] Several laboratories have reported the presence of free radicals in the lens nucleus and in the cortex.[15,57-60] The cortex contains high concentrations of glutathione which can prevent or abort free radical induced processes while the nucleus contains much lower levels of glutathione.

Comparison of the action spectra for production of fluorescent material in the lens and for photochemical destruction of tryptophan in aqueous solution suggests that the tryptophan residues in lens proteins and/or free tryptophan are the initial light absorbing, photochemically reactive species.[15] Accompanying the increase in fluorescent chromophores seen with in vitro experiments, and also as a consequence of aging, are increases in the yellow color of the lens and in insoluble protein levels, as well as a parallel decrease in both ultraviolet and some visible light transmission. Again, these changes are more pronounced in the nucleus (the extreme case being the brown nuclear cataract) than in the cortex and may be a consequence of the relative lack of reparative ability in the nucleus compared with the cortex.

Singlet oxygen may also be generated in the lens, as a consequence of the excitation of endogenous or exogenous photosensitizers in the presence of oxygen. The photosensitizers may be either certain drugs such a 8-methoxpsoralen or native components.[15,61] When human crystallins are exposed to a singlet oxygen generating system in vitro, changes are induced in the proteins which closely mimic those occurring in human lens proteins during aging and in senile cataractogenesis.[62] These include covalent crosslinking of the proteins, increased blue fluorescence, yellow pigmentation and formation of heavy molecular weight aggregates.

The superoxide radical is also present in the ocular lens. It can be generated via photosensitized, enzymatic, and non-enzymatic pathways. The lens contains superoxide dismutase to catalyze the dismutation of superoxide and form H_2O_2. It also possesses catalase and peroxidases which can detoxify H_2O_2 formed in the dismutation processes. Despite the presence of these protective mechanisms, it has been postulated that under certain circumstances (i.e., if these enzyme systems are compromised in some way) superoxide radicals generated in the lens or anterior chamber may cause deterioration in the cation pump and peroxidative damage to membrane lipids.[63] When whole rat lenses were exposed to a riboflavin photosensitized free radical generating system, the carrier-mediated transport function in these lenses was decreased.[64] This was attributed to an H_2O_2 intermediate. It has been postulated that relatively high levels of ascorbate (a superoxide radical scavenger) in the aqueous humor may have an additional protective role.[65] With in vitro systems, levels of ascorbate comparable to those present in the aqueous give significant protection against exogenously produced superoxide radicals.

Despite the fact that the lens possesses a variety of mechanisms to protect itself against free radical induced damage, under certain circumstances radical induced damage to lens membranes, structural proteins, enzymes and nucleic acids may occur. In a long lived species such as man, the consequences of even small amounts of damage may be cumulative, contributing significantly to both aging and cataractogenesis. It has been postulated, in other tissues as well as the ocular lens, that the cell membrane is a primary site where significant cumulative radical effects may contribute to both aging and pathologic processes. Membrane polyunsaturated fatty acids are particularly susceptible to radical initiated auto-oxidation processes which involve radical intermediates and are thus radical propagation processes. Once initiated the peroxidative process can alter the cells' permeability and cause fragility of the membranes. The initiating radical may be derived from a number of sources including sulphur and carbon centered radicals generated in proteins. Since biologic membranes have both intrinsic and extrinsic proteins closely affiliated with lipid components, free radicals generated at this site may contribute to lipid peroxidative damage. Alternatively, radicals generated during lipid peroxidative processes may interact with associated proteins to induce crosslinking. Crosslinking occurring in either intrinsic or extrinsic membrane proteins can further contribute to membrane damage by altering membrane conformation. Aside from producing obvious alterations in membrane function strictly as a consequence of structural alteration, these changes could serve to potentiate further radical induced damage.

Defense Systems of the Lens

Photo-oxidative Damage

It has long been esatablished that the human ocular lens contains very high levels of glutathione and ascorbic acid; the high GSH levels in the ocular lens are mainly confined to the cortex, with a much lower concentration present in the nuclear region.[1,15] It has also been domonstrated that the GSH content dimishes with age; this is particularly evident in the lens nucleus and may account for its susceptibility to the photochemically induced discoloration while the cortex, which has a much higher GSH level, remains transparent. It has been proposed that the lens is naturally endowed with high GSH and ascorbate levels since it is constatnly exposed to ultraviolet (UV) radiation throughout a person's lifetime.[1] These two compounds are very effective free radical scavengers and could abort radiation induced free radical reactions. The photodamage caused by a lifetime of cumulative UV radiation exposure (longer than 300 nm) has been attributed to photic mechanisms in which tryptophan acts as the initial absorbing chromophore, resulting in the eventual generation of free radicals which appear to be involved in the ensuing photochemical reactions.[57,58]

Recently, hydrogen peroxide has been implicated as a factor in the UV induced formation of at least one of the fluorescent pigments.[66] It has been postulated that H_2O_2 formed within the lens, being a good electron scavenger, could withdraw an electron from the (UV) excited indole ring of tryptophan. This might lead to the eventual destruction of tryptophan, producing small amounts of anthranilic acid which may be involved in the production of one or more of the lens fluorogens.[31,42,66.67] H_2O_2 can itself be produced by near-UV radiation action on tryptophan.[68] Thus a build-up of $H2^{O2}$ may also be significant in potential lenticular damage and the presence of adequate levels of GSH would also serve to protect the ocular lens in such a situation. Superoxide dismutase (SOD) and catalase are present in the normal lens in order to protect it from such oxidative damage.[69] H_2O_2 inhibits SOD activity in the lens extracts, and this inhibition is potentiated by 3-AT, while 3-AT alone has no effect on lens SOD; thus, it is postulated that endogenous catalase protects lens SOD from inactivation by H_2O_2.[69]

Singlet Oxygen

The photosensitizing action of the psoralen compounds has been correlated with the generation of cyclobutane photoaddition reactions with thymine in the DNA molecule.[70-72] A similar mechanism has been proposed for 8-methoxypsoralen (8-MOP) lens damage.[73] It has been demonstrated that 8-MOP can enter the lens and following photic stimulation, it can bind to lens proteins thereby enhancing whatever UV damage is already occurring in that individual, i.e., an increase in lenticular fluorescence and phosphorescence.[74] 8-MOP can also exert a photodynamic action in lens proteins by forming new photoproducts with certain aromatic amino acids in which singlet oxygen is involved.[75-77] That is, the triplet state of 8-MOP can react with ground state oxygen to generate $'O_2$.[78] The recent demonstration of an oxygen requirement for the photoreaction of 8-MOP with proteins[75-80] indicates that this compound can undergo the Type II reaction as well as the anaerobic Type I reaction with DNA, resulting in its binding to lens proteins and the permanent retention of the photoproduct(s) which can also function as new longer wavelength absorbing photosensitizers in the lens. Many reagents (antioxidants) are capable of quenching $'O_2$ and doubtless the lens contains its share of them.[81]

One of the immediate effects of radiation on biologic tissue is the production of strongly oxidizing species such as the hydroxyl radical. In order to obtain significant biological effects from the OH radicals (or similar strongly oxidizing species such as a singlet oxygen, the peroxide or the hydrogen peroxide radicals), they must a) be produced at or near the target, thereby directly inducing molecular damage, or b) there may be an energy transfer within the molecule (e.g., the OH radical attacks a protein and the energy is transferred along the peptide chain frequently terminating at an SH group in the chain), or c) the energy could migrate via lipid peroxidation. In all instances, the SH groups in biologic tissues play an important reparative as well as protective role. These groups may be small SH compounds (GSH) or part of a protein. Thus biologic reactions with strongly oxidizing agents appear to be involved with as well as determined by sulfhydryl groups. The GSH level within the lens is of extreme importance in ionizing radiation damage; a significant fall occurs almost immediately after an experimental animal is exposed,[82] while catalase and superoxide dismutase may also play an important role in protecting the lens against H_2O_2 and the superoxide radicals.[83]

VITREOUS

As previously noted, the vitreous is normally protected from UV radiation by the filtering action of the cornea (up to 295 nm) and by the lens as it ages (>295 nm). However, patients who have had their cataracts removed (aphakes and pseudophakes) have lost a significant and protective intraocular filter. The normal vitreous is a gel-like material composed mainly of water, collagenous protein, and long-chain carbohydrates. These compounds do not contain any significant chromophores absorbing above 250 to 260 nm, although a small number of aromatic amino acids are present. In this respect the cornea plays a much more significant role as a UV filter since it prevents UV radiation below 295 nm from entering the eye. However, the vitreous does contain some tryptophan residues and several cell types; the hyalocytes and fibrocytes. Thus, some chromophores are present that are capable of absorbing UV radiation longer than 295 nm, provided that the filtering action of the ocular lens is removed. There is some experimental evidence that exposure of the vitreous to UV radiation up to 320 nm results in shrinkage of the vitreous gel and denaturation of the collagen network.[84] There is also a decrease in the viscosity of hyaluronic acid preparations derived from UV exposed vitreous which can be attributed mainly to a decrease in molecular weight. Ultraviolet irradiation causes an increase in the reducing power of the polysaccharide solution due to a breakdown of the glucosidic linkages, an increase of the reducing end groups, and the formation of smaller fragments.[84] The absorption spectra of hyaluronic acid subjected to UV irradiation shows significant alterations with the development of new chromophores absorbing at approximately 267 nm. Other studies in which human vitreous gels were subjected to monochromatic UV radiation (280 to 300 nm) resulted in the generation of one or more fluorescent compounds. A 320-to-340 nm excitation and a 420-fluorescence emission peak could be demonstrated following four to six hours of irradiation, suggesting the possible photodegradation of certain amino acids.

It would thus appear that the cornea, which filters all UV radiation shorter than 295 nm, plays a major role in protecting the vitreous from UV damage. There is still insufficient experimental evidence to assess the effect of UV radiation longer than 295 nm, but there are indications that the vitreous is also sensitive to longer wavelenght UV radiation.[84] Thus the 295-to-400 nm filtering action of the ocular lens may also be of significance in protecting the vitreous.

RETINA

The fact that visible light is required in the cyclic process of shedding and renewal of the outer membrane discs which contain the visual pigments might explain the findings that even moderate but prolonged exposure to visible light, at thresholds of illumination well below those capable of causing thermal damage to the retina, can result in retinal pathology in a variety of experimental animals.[85-93] Aging is known to be characterized by a loss of rod and cone cells.[94] The recent observation that photic trauma can damage the receptors suggests a potential cumulative action of light resulting in an enhanced loss of visual cells over a period of years. That is, phototoxic effects may be cumulative in the normal aging process of the retina. Photon energies in the electromagnetic spectrum increase as the wavelength decreases, from 1.6 eV at 750 nm to 3.3. eV at 400 nm and higher energies in the UV wavelengths capable of penetrating to the retina in the aphakic or pseudophakic eyes. One would anticipate that photic damage would be greatest for UV radiation (320-400 nm) and short wave visible light in the blue region (400-475 nm) and decrease with increasing wavelengths of light, with the least photic damage occurring with red light. A variety of reports strongly implicate longwave UV and short wave visible radiation (320-450 nm) as a significant factor in retinal photodamage in primates as well as other experimental animals, and even in man.[1-6,95-100] These data are of particular concern in young patients as well as aphakes and pseudophakes who are on photosensitizing drugs and to all patients exposed to prolonged or above ambient levels of UVA radiation (e.g., occupational exposure industries where UV polymerization is employed, and certain activities such as sailing, snow skiing, etc.)

The spectral sensitivity of the human retina plays a role with respect to the efficiency of a specific wavelength in producing retinal damage. The ocular lens protects the retina from visible as well as UV radiation since it filters more of the shorter wavelengths of visible light (blue) compared with the longer wavelengths. Thus, the aging retina, which metabolically should be more susceptible to photic damage caused by visible light (as well as ultraviolet radiation), is in fact protected by the ocular lens which increasingly filters out the ultraviolet and shorter wavelengths of the visible spectrum as the person ages. This might explain why human retinas are normally capable of withstanding much higher thresholds of radiation intensity as compared with other animals such as the rat, rabbit and pigeon. The retinas of these animals can be damaged by levels of environmental light that are not damaging to the normal human eye.

Photochemical Damage

Although it has long been recognized that visible as well as infrared radiation is capable of causing thermal damage to the retinal when the eye is exposed to sufficiently intense sources at these wavelengths (solar retinopathy, xenon arc, and laser photocoagulation), the potential for nonthermal light injury has only recently become apparent. During the past two decades a growing body of literature has accumulated that attests to the deleterious effects of long-term exposures to low levels of visible light as well as UV radiation.[1-6,85-100] These investigations demonstrate that visible light at intensities well below levels that would cause thermal photocoagulation can damage retinal tissue in a variety of animals including man. This damage is manifested by electroretinographic and/or histopathologic changes.

Deleterious effects of long term exposure of the growing chick eye to light were reported in 1961.[85] The effects on the photoreceptor cells could not be explained in terms of thermal injury alone. The following year it was demonstrated that light exposure accelerated the degeneration of the photoreceptor cells in rats afflicted with hereditary retinal degeneration.[86] In 1965, Noel first demonstrated that the retinas of rats could be damaged by light of moderate intensity.[87] This report was followed by a series of papers which established that long-term exposure of normal albino rats to visible light at levels well below possible thermal damage, resulted in the degeneration and loss of rod photoreceptors.[88-92] The wavelength that produced maximum damage corresponded to the peak absorption of rat rhodopsin, and body temperature was noted to be an important factor in these photic effects. Photic damage to the retina after long-term exposure to low levels of visible light has now been reported in pigeons, rats, mice, rabbits, piglets, monkeys and even humans.[93]

A schematic outline of a typical course of retinal damage following long term exposure to light is shown in Figure 5. The initial effects involve the outer segments of the photoreceptro cells, in which the outer tip of the photoreceptor shows vacuole formation. The damage proceeds until the outer segment loses its normal lamellar structure and breaks off from the inner segment of the visual cell. As the outer segments are phagocytosed by the pigment epithelium, the inner segments develop pyknotic nuclei and also disappear. The final result is a retina in which most of the photoreceptor cells have disappeared but the remaining layers appear to be intact.

There is still a considerable amount of controversy regarding the effect of light on the pigment epithelium. Some workers believe that damage to the pigment epithelium occurs prior to the destruction of the photoreceptors; others believe that it occurs at the same time as photoreceptor cell destruction, and it has also been proposed that damage to the pigment epithelium occurs subsequent to the destruction of the receptor cells[1] Some investigators believe that damage to the pigment epithelium plays a major and primary role, with outer sigment degeneration being a secondary response to this damage and subsequent repair processes (inflammatory response). There is, however, considerable evidence of direct photic damage to the photoreceptor cells of the retina which occurs very soon after the animal has been exposed to light. It appears that the relative emphasis on photoreceptor cell damage versus pigment epithelial cell damage as the primary lesion, can be related to the use of pigmented versus albino strains of experimental animals. Thus, the role of melanin in retinal photopathology may be significant and awaits further elucidation. Recent studies on melanin haematoporphyrin photobinding suggest such a role for this pigment.[101]

Although most of the work relating retinal damage to visible light comes from studies with experimental animals, there is increasing evidence indicating that the human retina can also be damaged by relatively low levels of visible light.[93] The normal dark-adaptation reaction requires 30-40 minutes; and individual's sensitivity to light begins to increase immediately after being placed in the dark and reaches its normal level after 30 to 40 minutes, at which time there is no further increase in sensitivity. However, several investigators have demonstrated that exposure to strong sunlight for three to four hours results in dark adaptation thresholds that are elevated for 24 hours or more above normal levels and that there is a chronic effect on night vision that may persist for up to ten days.[95,96] Another study, invoving patients suffering from solar retinopathy, reported that there was complete recovery in about half of the eyes six months after the injury.[97] This would not be expected if the damage was due to retinal coagulation caused by thermal injury. It has been proposed that solar retinopathy in the rhesus monkey cannot be explained solely in terms of thermal injury; some type of thermally enhanced photochemical effect must also play a role. Some investigators believe that solar retinopathy can be accounted for almost entirely in terms of the photochemical effects of the shortwave visible (and UVA) components of the sun's spectrum.[100,102-104]

A recent study has demonstrated that a simulated solar spectrum (400 to 1400 nm) with a predominant portion of the energy in the short visible wavelengths was more damaging to the retina than a long wavelength spectrum (700 to 1200 nm), by a factor of 5.[100] These workers inferred that for a continuous solar spectrum, as the retinal irradiance is reduced and exposure duration is prolonged, thermal insult becomes less pronounced while photochemical effects with thermal enhancement become more prominent. This reasoning is supported by theoretic considerations. Thermal damage to the retina would be expected for radiation in the near-infrared region since the energy absorption takes place predominatly in the melanin granules of the pigment epithelium and choroid while the photoreceptors are not involved. The absorption of the near infrared by the melanin involves wavelengths with photon energies (<1 eV) that would essentially induce vibrational changes in the molecule without adversely affecting its molecular structure, that is, a thermal effect. However, the shorter the wavelength the greater the photon energy; in the UV and shortwave visible spectra (320-475 nm) the photon energies approach levels in which electronic excitation becomes the dominant mode of energy absorption (2.0 eV at 475 nm to 3.5 eV at 320 nm). Molecular systems in electronically excited states above the ground state are subject to photochemical reactions. Thus, overbleaching of the photorecptor pigments results in a new chain of metabolic events that appears to be capable of leading to irreversible as well as reversible damage to the visual cells depending on the duration and intensity of exposure to light.

A variety of theories has been proposed to explain the mechanisms for the light effect on the retina.[1,93,106] These include the photodynamic action of visible light on the photoreceptor cells resulting in the production of free radicals, which can lead to chain reactions involving peroxidation of the lipid membrane portion of the outer segments. Under normal conditions of light exposure, new disc membranes are continuously being formed to replace the peroxidized disc membranes that are being shed from the tip of the outer segment. A second theory concerns the possible effects of light on specific metabolic pathways in the retina, particularly the observation that the oxygen consumption of the retina is suppressed by steady exposure to light. A third possibility is that bleaching results in the formation of a toxic photoproduct, which under normal conditions is rapidly eliminated; but with chronic bleaching (due to long-term exposure) it accumulates as a toxic agent. It has been proposed that the chronic bleaching of the photoreceptor pigments would eventually damage the membranes of the outer segments since the loss of too many of the retinal molecules from rhodopsin would result in the accumulation of the protein moiety of the molecule (opsin). The free opsin appears to be an unstable molecule and requires the chromophore, retinal, to form a stable compound. Thus, the destruction of the disc membranes could simply be due to the loss of the stabilizing chromophore, retinal, from the visual pigment that cannot be regenerated by the normal processes of dark adaptation due to chronic light exposure and overbleaching.

RECOVERY FROM VISIBLE LIGHT DAMAGE

It has now been shown that visible light plays a normal physiologic role in maintaining the health of the outer segments of the visual cells. Thus, in man and other diurnal animals, a certain amount of photic damage followed by repair and recovery of the receptor cells is a significant factor in the maintenance of the photoreceptor elements and normal visual acuity. One would also predict that diurnal animals should be less susceptible than nocturnal animals to the same intensity of visible light, since nature must have provided them with a more efficient recovery mechanism, because photopic vision (daylight vision) plays such an important role in their daily lives.

The absorption characteristics of the ocular media (the cornea and lens) must be considered in determining the threshold level of visible light that is capable of causing retinal damage. As previously demonstrated, the human lens plays an increasingly important role with respect to its ability to filter UV radiation as it ages. The increasing yellow color of the lens nucleus with age also functions as a partial filter for visible radiation, particularly in the shorter wavelengths (in the blue region). Thus, the human ocular lens may serve an additional function in the older individual by virtue of its ability to filter out a significant portion of the visible radiation, particularly the shorter wavelengths (with the higher photon energy), thereby protecting the aging and metabolically less efficient retina from photic damage due to visible light.

It should be noted that the irradiance levels of energy incident on the retina (intensity measured as watts per square centimeter) is determined by the imaging properties (focusing properties) of the ocular media (the cornea and lens), the absorbing properties of the ocular media, and the size of the pupil. Utilizing these parameters, one can predict that the nocturnal animal should be more sensitive to the same threshold of light compared with the diurnal animal, and this appears to be borne out by experimental data.[1,93] Thus, the rat (particularly the albino rat) and rabbit appear to be the most sensitive animals to experimental retinal photo damage, with the diurnal animals (the monkey and human) displaying a decreasing order of sensitivity to the same intensity of visible light. There is as yet insufficient data available to determine the specific dose of photons absorbed, per receptor, for sustaining retinal damage. It is estimated that 1.5×10^3 to 1.5×10^4 photons/receptor/sec continued for a relatively long period of time are necessary to cause retinal damage by visible light.[93] Although the early studies indicated that visible light damage to the retina was irreversible, there is now evidence that the retina is capable of recovering from a moderate amount of photic damage, particularly if the pigment epithelium of the retina and the photoreceptor cell body are preserved.[105] These studies demonstrate that retinas from albino rats exposed to 750 to 1,000 footcandles (1.2 to 1.6×10^3 watts/cm^2) of light are capable of recovering within three to six weeks after such an exposure, as evidenced by a return of the electroretinogram to normal levels. The pathologic damage includes loss of the outer segments of the photoreceptor cells and moderate damage to the pigment epithelium. These damaged areas recover slowly with the latter cells showing the first recovery response followed by regeneration of the membranes to form somewhat irregular outer segments.

BODY TEMPERATURE AND LIGHT DAMAGE

It is important to note that the body temperature of the animal plays an important role in determining whether the damage is reversible or irreversible. There is a direct relationship between an increase in body temperature and the degree of reversibility of photic damage to the retina; a rise in body temperature by 3° to 5°C above normal will significantly increase the photic damage to the retina at the same exposure threshold compared with an animal kept at normal body temperature.[107]

Most of the studies on retinal pathology have utilized fluorescent and incandescent light sources. As previously noted, the spectral output of the fluorescent light source more closely approximates daylight, particularly in the UV region, while the incandescent illumination has a large infrared spectral output that serves as a heat source. Since even a relatively small increase in body temperature (approximately 3°C) can have a great influence on increasing the degree of light damage, it is important to differentiate experimental retinal photopathology from its purely photic versus its thermal mechanism.

OPHTHALMOLSCOPY, THE OPERATING MICROSCOPE AND RETINAL DAMAGE

One should also consider the potential problems with respect to indirect ophthalmoscopy and retinal damage. Several workers have demonstrated that indirect ophthalmoscopy is capable of producing retinal damage in primate eyes.[98,99] It should be noted that the standard method employed in indirect ophthalmoscopy involves the use of a 20-diopter convex lens placed between the light source and the patient's eye, which in effect will serve to act as an additional focusing element, thereby concentrating the light and energy per unit area onto the patient's retina (in addition to concentrating properties already inherent in the patient's own ocular media). It has been estimated that the amount of focal energy applied to the retina and choroid by the indirect ophthalmoscope is approximately 0.1 to 0.2 mW/cm^2, which approximates the amount of irradiance received at the retinal surface from the sun. However, it should also be noted that the indirect ophthalmoscope has 90 percent of its power in the infrared region (longer that 750 nm). The retinal irradiance levels with an indirect versus a direct ophthalmoscope have been measured and the data indicate a tenfold increase in retinal irradiance with the indirect ophthalmoscope.[108] It is estimated that at the patient's retina the total irradiance is composed of one-third visible light to two-thirds infrared radiation (750 to 1,4000 nm). Some workers have proposed that infrared filters should be incorporated into all ophthalmoscopes to prevent potential thermal damage from extensive indirect ophthalmoscopy. They also proposed that reasonably short exposures should be used when examining the posterior pole of the eye. Intense illumination and frequent re-examination at short intervals should be avoided. It whould be pointed out that the energy delivered during indirect ophthalmoscopy is only 200 times less than the energy that is capable of producing a retinal burn.

Lesions resembling central serious retinopathy have been demonstrated in primate eyes exposed to longwave UV radiation,[90,99] and recent reports have described clinically demonstrable retinal lesions in patients undergoing intraocular surgery with the operating microscope.[4,6] One must therefore consider the potential for retinal damage with these clinical techniques, particularly in certain conditions, such as retinitis pigmentosa, which might be accelerated by light exposure.[93] Photic damage has also been shown to result in pathologic changes in the pigment epithelium as well as the outer segments; this suggests the possiblilty that such damage would weaken the adhesions between the retina and pigment epithelium and potentiate retinal detachment.

SUMMARY AND CONCLUSIONS

Recent reviews have considered the possibility of ocular hazards resullting from ambient light exposure.[93,109,110] They indicate that ambient light levels are currently approaching the threshold level for permanent retinal damage (following chronic exposure). The levels of artificial illumination that we are exposed to at present vary between 20 and 50 footcandles (3.2 to 8.1 x 10^{-5}watts/cm^2). Although these levels of irradiance are well below the levels that are capable of producing retinal photopathology in primates and man, they have been shown to be of sufficient intensity to produce permanent as well as reversible retinal damage in certain experimental animals, particularly albino rats. The trend by lighting engineers toward higher levels of illumination (e.g., 100 to 1,000 footcandles) should be approached with extreme caution in view of the potential photic damage that could be incurred at these levels of illumination. It should also be noted that the lowest reported retinal damage threshold in primates occurs at wavelengths in the blue region of the spectrum, and the potential adverse effects of UV radiation on the retina must also be considered, particularly in the aphakic eye. Another point to bear in mind is the fact that the pigment epithelium is one of the major sites of primary photic damage; thus the melanosomes in the pigment epithelium may play a significant role as transducers of photic energy in the eye. These organelles seem to play a central role in both the thermal and chemical mechanisms of primary photic damage to the retina and may play a role in the pathogenesis of senile macular degeneration. One must also consider the role of photosensitizing agents in retinal photobiology. The fact that the psoralens absorb mostly in the longer wavelength UV spectrum (between 320 and 360 nm) has allayed concern about the risk of this drug to the retina., However, the ocular hazard from such photosensitizing drugs should be of concern in aphakic eyes that have lost their natural UV filter (the ocular lens), in pseudophakes and in young children (whose own lens has yet to develop as an effective UV filter.

PHOTOSENSITIZED RADIATION EFFECTS ON OCULAR TISSUES

A photosensitizing agent can be defined as a compound whose chemical structure endows it with the ability to absorb optical radiation (UV and visible) and undergo a primary photochemical reaction resulting in the generation of highly reactive and relatively long-lived intermediates (triplets, radicals, and ions) that can cause chemical modifications in other (nearby) molecules of the biologic system. Regardless of subsequent events, the primary event of photosensitization in ocular tissues appears to be the absorption of light by the photosensitizer molecule, eventually resulting in a complex of photosensitizer with nucleic acid or protein. Only the pyrimidine bases in the nucleic acids are susceptible to photosensitization, and in the proteins, histidine is the most readily altered of all the amino acid residues (either alone or as part of the protein) followed by tryptophan, tyrosine, cystine, and methionine.[1] Sensitized photo-oxidation reactions in proteins generally do not involve disulfide and peptide bonds, with chemical alterations occurring most frequently in the aforementioned five amino acid residues. Hundreds of chemical compounds are capable of acting as photosensitizing agents.[1,111-116] Such compounds include a wide variety of drugs used in routine medical practice as well as in industry, agriculture, and the home. The most common photosensitizing reactions involve the skin, although internal organs are also susceptible to phototoxic reactions.

There are several parameters that could influence the possibility and extent of photosensitized damage in the eye. These include; 1) the chemical structure of the drug in question and its absorption spectra; 2) the role of the blood-aqueous and blood-retinal barriers; 3) the age and/or the health of the patient; and 4) the oxygen concentration in the affected tissue. Certain drugs having a tricyclic (three fused aromatic rings), heterocyclic or porphyrin ring system are known to be efficient photosensitizers. The reason for this is 1) they have long-lived triplet states, 2) they have a low oxidation potential (Type I reaction) and, 3) their triplet state energy is such that transfer of energy to ground state oxygen is posible (Type II reaction).

In addition to the demonstrated direct photochemical action of UV radiation on ocular tissues, particularly the cornea, lens, and retina, there is the possibility of photobiologic damage by means of photosensitized reactions due to the accumulation and retention of certain drugs within these tissues. For example, after the 13 mm stage of development the ocular lens is completely encapsulated and never sheds its cells throughout life. Thus, photobinding a drug to the lens proteins and nucleic acids ensures its lifelong retention within the lens with the potential for enhanced photodamage if these compounds are capable of acting as photosensitizing agents. A similar situation exists in the neural retina which does not regenerate.

Only two groups of compounds (the phenothiazines and the psoralens) have been clearly identified as intraocular photosensitizing agents that are capable of causing photochemical damage to the choroid, the retina, and the lens in man as well as in experimental animals. This may be due to the screening effect of the blood-aqueous and the blood-retinal barriers. It is well known, for example, that it is difficult, if not impossible, to obtain an effective concentration of certain antibacterial, antimycotic, or antibiotic drugs in the interior of the normal eye, and this has been attributed to the relative impermeabliity of the blood-aqueous and the blood-retinal barriers.

Furthermore, It has already been demonstrated that the cornea, and particularly the lens as it ages, provide effective filters for UV radiation and the shorter wavelengths of the visible spectrum, thereby nullifying any potential photosensitizing action of drugs (that are activated at these wavelengths) which might accumulate in the posterior half of the globe. However, any photosensitizing agent that accumulates in the ocular lens or the retina might be a potential hazard if it becomes photobound to macromolecules within these tissues since it would now be permanently retained there.

The psoralen compounds are well known photosensitizing agents and have been used (under controlled conditions) in many dermatology clinics to treat Psoriasis and Vitiligo.[72,117] This form of phototherapy, commonly referred to as PUVA therapy, involves the ingestion of 8-methoxypsoralen (8-MOP) or relalted compounds, followed by exposure to UVA radiation (320 nm - 400 nm) for short periods of time. 8-Methoxypsoralen can be found in a variety of ocular tissues within two hours after the animal (rat, dogfish, monkey and human) is given a single dose (equivalent to a therapeutic level) and can become photobound to DNA and lens proteins if there is concurrent exposure to ambient levels of UVA radiation.[73-77] Since the mature ocular lens is a very effective filter for UVA radiation in most mammals (including man) there can be no photobinding of 8-MOP in the retina. However, UVA radiation can penetrate to the retina in aphakic and pseudophakic experimental animals and in young eyes (where the ocular lens still permits significant penetration of UVA radiation) and 8-MOP photobinding can occur in these retinas.

Psoralen-UVA (PUVA) therapy and cataract formation have now been documented in human cataracts as well as in experimental animals.[73,74,118-127] Cataracts from patients on PUVA therapy were subjected to high resolution phosphorescence spectroscopy. The lens proteins from these patients showed phosphorescence peaks identical (in shape and lifetime) with the previously reported 8-MOP lens protein photoproduct seen in experimental rat PUVA cataracts.[126] These data provide objective proof that this drug can generate specific photoproducts in human lenses which have been shown to be associated with the formation of PUVA cataracts in experimental animals. However this observation should not deter anyone from prescribing such therapy since simple and effective preventive measures are available. It should be noted that 8-MOP can be found in the lens for only 24 hours, provided that the eye is protected from UVA radiation.. Thus, many dermatologists are now providing proper UV filtering glasses to all their PUVA patients with instructions to put them on as soon as they ingest the drug and continue to wear them for a least 24 hours. They must be worn indooors as well as out of doors, since there is sufficient UVA radiation in ordinary fluorescent lighting to photobind the 8-MOP.[74,125] A two year follow-up study utilizing UV slit lamp densitography has proven the efficacy of this approach.[125,128] All the patients wore proper UV filtering glasses for at least 24 hours following drug ingestion, and none developed enhanced or abnormal lens fluorescence levels. In contrast, patients whose eyes had not been properly protected (those treated prior to 1978) had anomalous and enhanced lens fluorescence and some developed PUVA cataracts. It should be noted that PUVA therapy could pose a potential hazard not only to the ocular lens but to the retina in young people whose lenses are not effective UV absorbers and/or in aphakic or pseudophakic individuals, particularly if they are exposed to repeated PUVA treatments.[122,125-128] The intraocular lenses currently in use are excellent transmitters of UV radiation and thus provide less protection from UVA radiation than the natural lens or even ordinary glass (which absorbs UV radiation up to 320 nm). UV absorbing intraocular lenses are now being tested by several manufacturers and should provide a simple solution for preventing potential UVA photodamage to the pseudophakic retina.

Studies on the effects of PUVA in albino and pigmented mice, where much of the UVA can be transmitted to the retina, demonstrate that there are several receptor organelles which can be damaged by such exposure.[129] These include the rod outer sigments (ROS), the ellipsoid region of the rod inner segments, and the receptor nuclei. The damage involves vesiculation and disruption of the ROS, swelling of the ellipsoid as a whole with damage to the mitochondria, and necrosis of the nuclei. UVA by itself selectively causes more damage to the ROS, while 8-MOP in combination with UVA exposure results in far greater necrosis of the nuclei in addition to damaging the ROS and ellipsoids.[129,130]

The phenothiazines, especially chlorpromazine, have for a long time been recognized as having adverse ocular side effects.[131] Chlorpromazine is reported to be cataractogenic with pigment deposits appearing in the lens as well as in the cornea and conjunctiva. The role of NP 207 in retinopathy is well established while that of thioridazine and chlorpromazine is far less understood. There is a marked accumulation of chlorpromazine, prochlorperazine and thioridazine in the uveal tract of pigmented animals. The phenothiazines like other polycyclic aromatic compounds have a high affinity for melanin.[113] The relationship between such an affinity and functional alterations in vision is as yet unclear. With NP-207 the pigmentary pattern parallels the rod and cone disruptions. With other phenothiazines such as thioridazine few side effects have been reported when they are administered in doses of less than 800 mg per day. Chlorpromazine has been used extensively as an anti-psychotic. It also binds to melan and causes relatively minor pigmentary changes of the fundus though some alterations in visual functions have been noted.

Allopurinal is a commonly used antihyperuricemic agent in treating Gout. Scattered reports have appeared regarding the possible relationship between the development of lens opacities in relatively young patients (2nd to 4th decade) and chronic ingestion of this drug.[132-134] Cataracts obtained from eleven patients on chronic allopurinol thereapy (> 2 years) were subjected to high resolution phosphorescence spectroscopy. The characteristic allopurinol triplet was demonstrated in all the cataracts. Identical spectra were obtained on normal human lenses incubated in media containing 10^{-3} M allopurinol and exposed to 1.2 mW/cm^2 UV radiation for 16 hours; control lenses (irradiated without allopurinol) were negative. Similar data were obtained on lenses from rats given one dose of allopurinol and exposed to UV radiation overnight. However, the allopurinol triplet could not be demonstrated in normal eye bank lenses derived from patients who had been on chronic allopurinol therapy for more than 2 years without developing ocular problems.[134] These data suggest that allopurinol can act as a cataractogenic enhancing agent in some patients when it is permanently photobound within their lenses (probably as an additional extrinsically derived photosensitizer). Thus, chronic allopurinol therapy (by itself) does not necessarily result in the retention of allopurinol unless it becomes photobound. The relationship between levels of UVA exposure, circulating allopurinol levels (and renal function) in the genesis of photosensitized allopurinol cataracts will require further studies.

Experimental cataracts have been reported following Tetracycline administration, an effect which may be due to photosensitization.[135] Fraufelder lists erythemal reactions of the eyelids and edema, photosensitivity and erythema multiforme as other ocular side-effects of this drug.[116] Its action spectrum ranges between 350-420 nm. Since its mechanism of action is poorly understood, it is frequently labelled as phototoxic and possibly photoallergic.[111] Acute transient myopia, blurred vision, diplopia and papilledema, though rare and for the most part reversible, have also been associated with the administration of tetracyclines.[111,116] The combined administration of tetracycline and minocycline can result in pseudotumor cerebri.[116] Since extraocular paresis and/or parlysis and papilledema can be caused by pseudotumor cerebri, these signs and symptoms are probably secondary to the pseudotumor and not directly related to any photosensitizing or toxic effects of the drug.

Griseofulvin is an antifungal agent which can cause severe allergic reactions with involvement of the eyelids and erythema multiforme-like rashes.[111] Though rare, these side effects can occur when the medication is given in heavy doses over extended periods of time and are probably due to a photoallergic mechanism.[111] Transient macular edema has been reported with this drug.

Adramycin is an anthracycline antibiotic that is also used as a chemotherapeutic agent in treating cancer. Adramycin can affect cells by intercalating with DNA, membrane binding, and lipid peroxidation. The most thoroughly documented action of Adriamycin is DNA intercalation.[136] The consequences of this intercalation include blockage of DNA, RNA, and protein systhesis; inhibition of DNA repair and fragmentation of DNA. Adramycin also binds to cell surfaces and alters membrane function at concentrations below those required for DNA intercalation. Adriamycin is reduced to a semiquinone free radical by cytochrome P_{450}. The semiquinone transfers an electron to molecular oxygen, producing the superoxide radical ion.[137] This leads to a free-radical chain reaction that results in peroxidation of unsaturated fatty acids. Superoxide generation may also lead to single-stranded scission of DNA.

Naladixic acid therapy can also be associated with mild visual disturbances and changes in color perception, with reversible papilledema and 6th nerve palsies.[11].

Other drugs with photosensitizing photoallergic and/or phototoxic properties include the sulfonamides, the oral hypogleycemic agents, antimalarial agents (chloroquine), and some of the oral contraceptives.[116]

The increasing interest in using porphyrin derivatives (HPD) for phototherapy (and photodiagnostic procedures) merits careful evaluation with respect to their phototoxic (or sensitizing) potential. The porphyrin derivatives absorb over a wide range in the UV and visible region of the electromagnetic spectrum and the fact that they appear to be slowly metabolized (HPD) can be retained for 3 months after injection[138]) necessitates that adequate precautions should be taken when such therapy is employed. These compounds can exert a photosensitizing action via the Type I and Type II reactions. The photodynamic action is mediated via singlet oxygen and has been shown to polymerize lens proteins in vitro.[139] The porphyrin induced photochemical reactions also involve OH radicals and have been implicated in the generation of H_2O_2, [138] thus the potential for ocular damage certainly exists. Patients undergoing HPD therapy must be monitored for ocular side effects, and they should also be informed about the potential for severe sunburns, particularly within the first 3 months following therapy.

There has been a recent resurgence of interest in the therapeutic uses of topical vitiman A acid (retinoic acid) and closely related compounds (140-142) particularly for skin conditions such as Acne and related disorders and Psoriasis. In addition, such compounds have been tested as a method for treating corneal Xerophthalmia, an ocular condition caused by a severe Vitamin A deficiency.[143,144] Considerable success has been claimed with such a therapeutic regime; however, the oral administration of Isotretinoin has resulted in some side effects; corneal opacities have been reported in a patient receiving this drug.[145] Topical retinoic acid in treating experimental corneal xeropthalmia has met with mixed results. While little is known about the specific mode of action of such drugs, the possibility of phototoxicity (and /or photosensitization) should be considered, particularly with respect to the eye. Patients undergoing clinical trials with these drugs should have careful ocular examinations prior to instituting therapy and be re-evaluated at specific intervals to assess their ocular status.

CLINICAL LENS FLUORESCENCE STUDIES

Since laboratory studies have demonstrated enhanced fluorescence in the ocular lens associated with aging and drug therapy and human photosensitized cataracts have recently been reported, a method to monitor lens fluorescence in vivo has been developed.[146,147] A new slit lamp densitographic apparatus (based on the Scheimpflug principle) capable of accurately and reproducibly recording visible changes in lens density as it ages was recently introduced.[148,149] This apparatus has been modified to utilize UV radiation (300-400nm) to measure and quantitate the age related fluorescence levels in the normal lens in vivo and correlate them with in vitro data.[1,15,16,21,146,147] Visible and UV slit lamp photographs taken with the Scheimpflug (Topcon SL45) camera on normal eyes and corresponding densitograms show increased lens fluorescence with age.[146,147] A series of UV and visible slit lamp photographs of normal patients ranging in age from 5 years to 82 years demonstrate a lack of fluorescence in the young lens and a progressive increase in fluorescence with age (Figures 6-8). These data can be expressed in graphic form (Fig 9) showing the normal age related increase in lens fluorescence (in vivo) which corresponds well with the in vitro data (Figs. 10 and 11) previously reported.[15,16,21] The in vitro studies were performed on lenses from normal eye bank eyes and represent two (non-tryptophan) fluorescent peaks obtained by fluorescence spectroscopy.

Aside from demonstrating the normal age related increase in lens fluorescence, abnormal enhanced fluorescence caused by occupational (or accidental) exposure to higher levels of UV radiation can also be detected. This is shown in Fig. 12 obtained on a 40 year old patient exposed to excessive UV radiation in his workplace. The increased fluorescence can easily be appreciated by comparing this lens with a normal 40 year old eye (Fig. 13). Enhanced fluorescence and/or abnormal fluorescence emission can also occur in patients on PUVA therapy and failure to properly protect such patients from all UV radiation exposure for at least 24 hours following ingestion of the drug can result in cataract formation as shown in Fig. 14. This 52 year old psoriatic patient received four years of intermittent PUVA treatmetn (without proper eye protection). Although many Dermatology clinics now provide all PUVA patients with proper UV absorbing or reflecting spectacles, data obtained on a series of patients who were treated prior to 1977 (when the potential for photosensitized lens damage form psoralen therapy was first demonstrated[74]) show a significant elevation of one of the lens fluorescence peaks (Fig. 15). In contrast, patients who have been on D-Penicillamine therapy (for a variety of diseases) tend to have lower lens fluorescence intensities (Fig. 15). This is due to the fact that D-Penicillamine (which is an excellent free radical scavenger as well as a chelating agent) is capable of entering the lens, both in vivo as well in vitro.[43,58] As a free radical scavenger, D-Penicillamine aborts the UV induced free radical reactions thereby preventing lenticular photodamage.

These studies demonstrate the feasibility of obtaining in vivo lens fluorescence data which are objective, reproducible and can be quantified. Thus UV slit lamp densitography can be used to objectively monitor one parameter of lens aging (fluorescence), as well as photosensitized lens damage, at a molecular level months to years before visible opacities become manifest by conventional slit lamp examination, and measures can be instituted to at least retard if not prevent such lens opacities.

In addition to performing in vivo lens fluorescence measurements, the same photographs can also be utilized (with proper software) to obtain biometric measurements on these eyes including: (1) radius of curvature of the anterior and posterior cornea and corneal thickness; (2) depth of anterior chamber; (3) radius of curvature of the anterior and posterior lens surfaces and lens thickness. Thus the clinician can now obtain reproduceable biometric data on the anterior segment ocular tissues and structures by simply utilizing the Schiempflug slit lamp photographic method. These data will provide an accurate method for monitoring age related changes in the normal eye (e.g. - A.C. diameter, lens thickness, lens density, growth of lens nucleus, and increased lens fluorescence). The progress of lenticular opacification can also be followed utilizing visible light densitography[146] and lenticular and corneal fluorescence data can be obtained concurrently by substituting broadband UV radiation for the visible exciting light with appropriate filters.

Laser light scattering can also be employed as an in vivo method to monitor the development and progression of light scattering elements within the lens before they become manifest with our conventional slit lamp examination.[150,151] Aside from the foregoing biophysical techniques already available, Raman and Nuclear Magnetic Resonance spectroscopy will, in the near future, also become available for detecting and measuring molecular changes in the living lens at a very early stage in their development.

In Nuclear Magnetic Resonance examinations, patients are subjected to long-wavelength radiation in a large chamber that exerts a magnetic field around them. Unlike radiation from a CT scan, NMR radiation is non-ionizing and thus harmless. In essence, it energizes atomic nuclei in the patient's body. The nuclei do not remain energized but tend to relax back to their normal, less energetic ground state. In doing this they give off energy, or "resonate"--thus, the term nuclear magnetic resonance. Current studies utilizing ^{31}P NMR spectroscopy enable the investigator to monitor organophosphate metabloism in the lens in vivo (surface scanning) as well as in vitro.[152-156] Such data provide dynamic rather than static information about the general metabolic state of this organ and quickly reflect changes in high energy phosphates (ATP, ADP, etc.), sugar phospates, inorganic phosphate and so forth. For example in experimental sugar cataracts (glucose, galactose, xylose) one can measure the accumulation of sugar alcohols and the concomitant alterations in organophosphate levels as sooon as these metabolic changes develop and well before any opacities become manifest. Other forms of NMR spectroscopy permit us to monitor changes in sodium and amino acids and detect very early changes in molecular aggregate formation as reflected by alterations in the lens water compartments.[157-159] Although such studies are still undergoing laboratory evaluation, sufficient data has accumulated to demonstrate the feasibility of applying one or more of these techniques to human studies in vivo. In essence, one will obtain a more sensitive type of CAT-scan capable of detecting molecular dysfunction within the eye without exposing it to ionizing radiation.

THE ROLE OF COMMERCIAL SUNGLASSES

Because of the confusion and controversial claims regarding the efficacy of commercially available sunglasses in protecting the eye from UV photodamage, a large series of such lenses have been analyzed to determine their transmission characteristics. These studies[160] are in general agreement with an earlier report[161] and demonstrate a wide variation in the UV transmission characteristics of the sunglasses evaluated, ranging from 1.5 - 40%, with similar transmission values noted when tested for more discrete wavelengths (340-380 nm). Only the NOIR, Spectra-Shield, Silor, Univis, and UV 400 lenses were >99% effective in filtering all the UV radiation. It should also be noted that visible radiation is significantly decreased in darkly tinted sunglasses, while still permitting some long wavelength UV transmission. In patients with blue, gray and hazel eyes, a 50% or more decrease in visible radiation can result in pupillary enlargement of 0.25 mm thereby increasing the effective dose of radiation incident on the intraocular tissues.

VDT's AND THE EYE

The recent controversy regarding ocular problems which have been reported in workers using VDT's may turn out to be beneficial and opportune. In contrast with the indifference and ignorance with which we embraced the development of the X-ray (in the not too distant past), the community at large, as well as the scientific specialists, are now well aware of possible dangers in misusing electromagnetic radiation. We now have the ability to monitor radiation emission levels from our technological marvels and obtain reasonably accurate measurements on most wavelength emissions of interest. We also have a considerable body of ever expanding scientific knowledge which enables us to correlate specific radiation emission levels with threshold doses for possible photobiologic damage. Such measurements have recently been performed by scientists by the Bureau of Radiological Health, Bell Laboratories and NIOSH.[162-164] Scientists at the BRH measured ionizing radiation (e.g., X-ray) emission levels on 125 VDT's; of these, 34 VDT's were also measured for non-ionizing radiation emission [UV, visible, infrared (IR), microwave and other radiofrequency (RF) emissions]. A smaller number of VDT's were similarly evaluated by Bell Laboratory scientists. These data indicate that the VDT's "emit little or no harmful radiation under normal operating conditions."[162] The specific emissions that were detectable were all well below the current national and international safety standards.

Aside from "ocular fatigue", questions have been raised regarding a possible relationship between VDT radiation emission and "organic" ocular photodamage, particularly to the ocular lens. Of the various wavelengths in the electromagnetic spectrum, UV radiation and ocular photodamage have received considerable attention during the last two decades. The best available current experimental and epidemiologic evidence does not indicate that the level of UV radiation emitted by the VDT's is capable of exerting any deleterious effects on the ocular lenses of personnel using these terminals. We should, however, pay more attention to the workplace with respect to the types of lighting (their UV emission levels) used in these environments and the reflectance level[165] of work surfaces (including reflectance of painted walls, desks, etc.) in order to maintain total ambient UV radiation exposure at minimum levels. Our own ocular lens serves us well as a natural filter for removing the UV radiation that penetrates into the eye, thereby protecting the underlying retina which has been shown to be quite sensitive to rather low levels of UV radiation. Thus particular care must be taken to protect the aphakic and pseudophakic individuals from potential low level UV radiation damage. A similar situation pertains to some patients who are receiving photosensitizing drugs. Fortunately the levels of UV radiation emited by the VDT's are approximately one thousand fold lower than the amount shown to cause retinal photodamage in experimental primate studies.

Further research should be encouraged particularly in the areas relating to non-ionizing photobiologic radiation damage in order to clarify and better define the molecular mechanisms resulting from exposure to UV, IR, microwave, and RF radiation. It is also important to determine whether damage can result from cumulative low level exposure over a lifetime, and whether a synergistic effect could accrue from low level exposure to broadband radiation (e.g., UV + microwave, ionizing + non-ionizing).

Finally, it should be noted that we now have the capability of protecting the eye from potential UV photodamage by special eyeglasses and similar UV absorbing materials could be employed at the manufacturing end to prevent UV radiation emission from our ever increasing array of technological products.

POTENTIAL HAZARDS FROM OZONE DEPLETION

The foregoing discussion has demonstrated that ambient UV radiation is capable of inducing damage to various ocular tissues, particularly the cornea, lens and retina. The latter two organs are protected from shorter wavelength UV radiation by the cornea which acts as a very effective filter for the 280-300 nm wavelengths. However, longer wavelength UV (above 300nm) has now been shown to play a significant role in the generation of at least one form of aging cataract, the brown (nuclear) cataract. In the aphakic or pseudophakic individuals (who have lost the filtering protection of their own lenses) the retina might also be susceptible to photochemical damage. The aphakic primate retina can be irreversibly damaged by very low exposure doses (ca, 5mW/cm^2) of UV longer than 325 nm. Furthermore, photochemical damage to ocular tissues is potentiated by certain photosensitising drugs and chemical reagents. Since current levels of solar and man-made UV radiation have already been shown to exert photochemical damage to these ocular tissues, any decrease in the ozone layer could therefore be accompanied by a significant increase in photodamage to the cornea and lens in the phakic individual and the retina in the aphake or pseudophake and children whose own lenses have not as yet become an effective filter for UV radiation.

THERAPY

Radiation Filters

The section on the effect of ultraviolet and visible radiation on the aphakic or pseudophakic eye has considered the mechanisms involved in ocular photodamage caused by optical radiation; i.e., non-ionizing radiant energy (280 nm - 1400 nm) which is present in our environment. As noted, the simplest and most effective preventive therapy for ultraviolet induced cataracts involves the use of spectacles which are capable of filtering out 99+% of the ultraviolet radiation (300-400 nm) which penetrates through the cornea. The development of ultraviolet-visible slit lamp densitography now enables us to detect lenticular ultraviolet photodamage at a molecular level, months to years before the opacities become manifest with our conventional slit lamp examination. Such a screening procedure will detect enhanced or abnormal lens fluorescence for any particular age group (by decade) thereby alerting the clinician that the patient has had excessive ultraviolet exposure. Studies indicate that any patient whose lens fluorescence levels are >30% above the amount present for his age group (by decade), should be considered a potential candidate for the development of ultraviolet cataracts, particularly the brown nuclear cataract.[1,16,128] Such enhanced lens fluorescence can be caused by occupational or recreational exposure to prolonged solar ultraviolet radiation in those people living in the "sun belt" areas of the United States, or by exposure in industries where ultraviolet radiation is employed in research and development or manufacturing procedures. Further progression of this type of lens fluorescence can easily be prevented by prescribing proper ultraviolet filtering glasses to such patients.

Since a certain amount of ambient ultraviolet exposure exerts a positive photochemical influence on the developing lens during childhood, inducing the generation of pigments so that the lens becomes an effective filter for ultraviolet and short wavelength visible radiation, (thereby protecting the aging and metabolically less efficient retina from potential photodamage) ultraviolet protective spectacles are not recommended for the general population, nor are they required. Such spectacles are only required when enhanced or abnormal fluorescence is present. If the ultraviolet slit lamp densitography screening procedure demonstrates abnormal lens fluorescence, it may be indicative of current or past ingestion of photosensitizing drugs or chemicals. Such patients should also be given ultraviolet absorbing spectacles with sidepieces (to prevent reflected radiation from entering the eye), and, depending on the mode and frequency with which these patients are ingesting the photosensitizer, they may only need to wear them for 24 hours after ingesting the drug.

Since the aging retina is particularly sensitive to ultraviolet and shortwave visible radiation, such spectacles are also recommended for all aphakes and pseudophakes irrespective of their site of domocile (i.e., not just those living in the sunbelt areas), or occupation. It is important to note that none of the contact lenses are capable of filtering ultraviolet radiation; in fact, all the plastic contact lenses transmit much more ultraviolet radiation shorter than 320 nm than does ordinary glass. The same applies to most of the intraocular lenses currently employed although many manufacturers are now eagerly attempting to develop and market ultraviolet filtering intraocular lenses. Once again, a word of caution is advisable. To be truly effective and protective, such intraocular lenses must filter 99+% of all ultraviolet radiation between 300-400 nm and at least 50-75% of the shortwave visible radiation between 400-475 nm.

Medication

Aside from the use of ultraviolet and shortwave visible radiation filters, the potential exists for a medical approach to protect the lens from direct and photosensitized optical radiation damage. A variety of investigators have noted that D-penicillamine exerts a significant protective action both in vivo and in vitro and prevents experimental ultraviolet radiation photodamage and/or cataracts from developing in spite of direct ultraviolet exposure.[15] This drug is an effective free radical scavenger as well as chelating agent. Its latter action is the basis for its clinical use in treating Wilson's disease. It efficacy as a free radical scavenger within the lens has been demonstrated by in vitro and in vivo experiments in animals[16,58] where it aborts radiation induced free radical damage and prevents the subsequent photochemical reactions from being promulgated. Ultraviolet slit lamp densitography studies on a series of patients who had been on one or more years of D-penicillamine therapy (for a variety of non-ocular conditions) all had significantly decreased lens fluorescence values compared with their control peer groups. This suggests that medical therapy to inhibit or prevent progression of radiation induced lenticular photodamage is a distinct possibility in the future. Such therapy could be applied locally in the form of drops, ointment or a prolonged release form of medication, in much lower concentrations than currently being employed for treating Wilson's disease or certain forms of arthritis (i.e., in microgram rather than milligrams quantities) thereby diminishing if not obviating some of the side effects currently seen with D-penicillamine therapy. Aside from this specific drug, there are a significant number of other free radical quenchers or scavengers which, at least in theory, should be effective as possible forms of medical therapy for radiation cataractogenesis. However, prior to such therapy becoming available, it must be proven effective as well as safe.

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WRITTEN TESTIMONY

REGARDING

STRATOSPHERIC OZONE MODIFICATION

BY

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FOR THE

U.S. SENATE COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS'
SUBCOMMITTEE ON HAZARDOUS WASTES AND TOXIC SUBSTANCES
AND THE
SUBCOMMITTEE ON ENVIRONMENTAL PROTECTION

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THE EFFECT OF SOLAR UV-B RADIATION ON MARINE ORGANISMS: AN OVERVIEW

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Abstract

Various experiments have demonstrated that UV-B radiation causes damage to fish larvae and juveniles, shrimp larvae, crab larvae, copepods, and plants essential to the aquatic food web. These damaging effects include decreases in reproductive capacity, growth, survival and other functions of these organisms. In natural marine plant communities a change in species composition rather than a decrease in net production is the probable result of enhanced UV-B exposure. The change in community composition may result in a more unstable ecosystem and would likely have an influence on higher trophic levels, e.g., shellfish and finfish. A decrease in column ozone would diminish the near-surface season of invertebrate zooplankton populations. Whether the population could endure a significant shortening of the surface season is unknown.

The direct effect of UV-B radiation on food-fish larvae closely parallels the effect on invertebrate zooplankton. Information is required on seasonal abundances and vertical distributions of fish larvae, vertical mixing, and penetration of UV-B radiation into appropriate water columns before effects of incident or increased levels of exposure to UV-B radiation can be predicted. However, results from one laboratory study involving anchovy larvae supported the conclusion that a 20% increase in incident biologically damaging UV-B radiation (a result of about a 9% decrease in the atmospheric ozone column) could result in the death of all of the larvae within a 10-meter mixed layer in April and August after 15 days. It followed that about 8% of the annual larval population throughout the entire water column could be directly killed by a 9% decrease in column ozone.

Introduction

Aquatic environments include shallow freshwater ponds, lakes and streams, fresh and saline inland seas, brackish-water marshes, swamps and estuaries, and a wide variety of marine habitats. The marine habitats extend from inshore coastal regions, surf zones, and fringing reefs to the wide spaces of the open sea and the abyssal deeps. Inland waters cover less than 1% of the earth's surface, while the oceans extend over more than 70% of the earth's surface.

Because of the relatively small volume of inland waters, freshwater plant production contributes only a few percent to the total global productivity (Table 1). Marine systems, covering a vast area, contribute significantly to global productivity, an amount equivalent to half the terrestrial plant production. The coastal kelp forests have productivities said to rival those of tropical rain forests, generally considered the world's most productive plant ecosystems (Mann 1973; Lieth 1975). Of the five major marine habitats considered in Table 1, the microscopic plants of the open sea are the most productive, contributing 75% of the marine production or 24% of the global total.

Table 1. Representative primary production and plant biomass summaries of the earth (adapted from Whittaker and Likens 1975).

Ecosystem Type	Area (10^6 km^2)	Net Primary Production (g m^{-2} y^{-1})	Mean Plant Biomass (kg m^{-2})
TERRESTRIAL			
Tropical rainforest	17.0	2200	45
Tropical seasonal forest	7.5	1600	35
Temperate evergreen	5.0	1300	35
Temperate deciduous	7.0	1200	30
Boreal forest	12.0	800	20
Woodland and shrubland	8.5	700	6
Savannah	15.0	900	4
Temperate grassland	9.0	600	1.6
Tundra and alpine	8.0	140	0.6
Desert and semi-desert scrub	18.0	90	0.7
Extreme desert, rock, sand and ice	24.0	3	0.02
Cultivated land	14.0	650	1
Swamp and marsh	2.0	2000	15
Lake and stream	2.0	250	0.02
Total Continental	149(29%)	773(68%)	12.3(99.8%)
MARINE			
Open ocean	332.0	125	0.003
Upwelling zones	0.4	500	0.02
Continental shelf	26.6	360	0.01
Algal beds and reefs	0.6	2500	2
Estuaries (excluding marsh)	1.4	1500	1
Total Marine	361(71%)	152(32%)	0.01(0.2%)
WORLD TOTALS	510	333	3.6

Photosynthesis, the conversion of radiant energy from the sun into chemical energy (food), is the basis of almost all life on the earth. Photosynthesis requires light, but adequate sunlight seldom penetrates to the bottom of natural waters; thus, aquatic photosynthesis is largely confined to a relatively thin layer at the water surface termed the euphotic zone, the surface layer where plants create more chemical energy by photosynthesis than they use for their own metabolism.

Organisms in fresh water or the oceans are either swimmers (nekton), bottom-dwellers (benthos), or drifters (plankton). Plankton can be either plants (phytoplankton) or animals (zooplankton). An important zooplankton group, the ichthyoplankton, is comprised of the drifting eggs and larvae of many species of fish. Zooplankton in general contain nearly all groups of aquatic animals, at least for some phase in their life-history, such as the egg and/or larval stage. Zooplankton are found at all depths, depending on species and season, but are most abundant in the sunlit upper 100 m, where the bulk of their food, including phytoplankton, is found. As feeding progresses from the phytoplankton through the zooplankton to fish and other higher organisms (the food web), the chemical energy generated by aquatic photosynthesis becomes more and more concentrated into organisms of larger size, reaching organisms suitable for harvesting for human use.

Marine ecosystems are highly dynamic and of bewildering complexity. Many of the fundamental processes affecting the abundance of marine resource stocks are only poorly understood. For example, the complexity of food webs in the ocean appears to be much greater than for the case of terrestrial populations (Larkin 1978). But little is known in a quantitative sense about marine ecosystems, although some geographical areas are currently under intensive investigations.

Many other sources of complexity in marine population dynamics exist. Simple density-dependence mechanisms, for example, can theoretically result in so-called "chaotic" oscillations in population abundance (Levin and Goodyear 1980). Most fish stocks do in fact undergo significant irregular fluctuations, the underlying causes of which are not well-understood. In most cases both density-dependent and density-independent effects are probably involved.

For any given level of fish mortality, the productivity or equilibrium yield of a stock depends upon growth, recruitment, and natural mortality. Growth is relatively easy to measure and understand; recruitment is relatively easy to measure but difficult to understand; and natural mortality is both difficult to measure and difficult to understand. The phenomena that are difficult to measure or understand are usually masked by the standard productivity analysis.

As early as 1925, scientists were aware of damaging effects from the ultraviolet component of sunlight even on aquatic organisms (Huntsman

1925; Klugh 1929, 1930; Harvey 1930; ZoBell and McEwen 1935; Giese 1938; Bell and Hoar 1950; Dunbar 1959; Marinaro and Bernard 1966). It was shown at these early dates that different species were apparently variously sensitive to UV radiation, and that this differential sensitivity might relate to the depth at which the species were found.

There have been several more recent studies on the effects of UV-B radiation on a variety of marine organisms (NAS 1979; NAS 1984). Regardless of species investigated, each study has potential importance through the role of the particular organism in its environmental or food-web context. Some studies, in addition, have considered economically important zooplankton species, such as larval stages of certain shrimp, crab, and fish. Recent literature reviews (Calkins 1982; Worrest 1982, 1983a,b) have summarized the results of most of these studies.

Physical Effects on Organisms

UV-B radiation is readily absorbed by proteins and nucleic acids, and is effective in inducing photochemical reactions in plants and animals (Caldwell 1971; Murphy 1975; Giese 1976). Even though proteins and nucleic acids are commonly involved in biological responses to UV-B radiation, the action spectra for tissue damage in many organisms may differ because of wavelength-dependent refraction, reflection, or absorption, and hence protection, by outer tissues (Cheng et al. 1978).

The usual effects of environmental stress (e.g., pollution) are changes in overall productivity and reductions in species diversity. Diversity is associated with stability in ecosystems, allowing alternate routes and choices within food webs. In field situations under slight stress, one often cannot measure changes in productivity or size of specific populations, but sometimes changes in species diversity can indicate that adverse effects are occurring. With loss of species an ecosystem loses some of its natural resiliency and flexibility. In aquatic ecosystems we must consider a great number of species, with different life stages and different trophic levels. With increased knowledge of ecosystems and the physical/chemical environment, the effects of enhanced solar UV radiation on single species could be placed in perspective.

The biological response to ultraviolet radiation can be very wavelength dependent. This wavelength specificity makes it necessary to develop weighting functions to express ultraviolet radiation in biologically meaningful terms. Biological action spectra normally serve as the basis for these weighting functions. The weighting function is normally taken as an action spectrum for a particular response. Several action spectra have been developed describing the response of biological systems to UV-B radiation (Caldwell et al.

1986). Examples are a representation of a DNA response (Setlow 1974), a generalized plant response (Caldwell 1968).

Based on an analytic characterization of ultraviolet sun- and skylight, a 10% ozone reduction at 45 degrees north latitude would result in only a 1% increase in total solar ultraviolet (290-360 nm) daily exposure at the surface of the earth. This would be of minimal consequence if radiation throughout the solar spectrum were of equal biological effectiveness. However, when the biological weighting functions based on the action spectra are employed, a very different picture emerges. Based on DNA damage, a 10% ozone reduction would result in a 28% increase in biologically effective radiation (Table 2). The generalized plant response (damage) would increase by 21%.

The increased exposure to biologically effective (DNA, Plant) ultraviolet radiation resulting from a 10% decrease in stratospheric ozone would correspond, from a UV-exposure standpoint, to migrating over 30 degrees toward the equator--a change of ecological significance. Levels of UV-B irradiance vary latitudinally, with the highest exposures in the tropics. The current difference between the extremes of exposures is about 3- to 6-fold, but biota are presently adapted to the levels that are normally experienced at their current locations.

Table 2. Relationship between ozone depletion and biological effectiveness of increased UV-B radiation.

Ozone	Increase in UV Radiation		Increase in Effectiveness[a]	
Decrease	290-320 nm	290-360 nm	DNA	Plant
10%	8%	1.1%	28%	21%
20%	17%	2.4%	67%	49%
30%	27%	3.7%	125%	85%
40%	38%	5.2%	213%	132%

[a] Action spectra are referenced to 300 nm = 1.00.

We are obtaining increasing evidence that marine ecosystems change as a result of natural as well as man-made events. Many of these changes occur on time scales of tens of years. The past changes may be associated, in some general context, with gradual climatic trends, but ecological changes seem to occur quite rapidly, with relatively persistent communities existing in the intervening periods. In any region rather than having one "ecosystem," there are two, or possibly several, alternatives--each resilient to some range of variability but capable of being replaced if some factors in the environment pass a threshold. To this natural episodic response, we must now add the effects of anthropogenic perturbations. The evidence suggests that we shall continue to have such changes but shall have added questions of attributing cause to natural stresses or to stresses resulting from human activities. Although we may not be able to predict when, or possibly why, such changes occur, they can be regarded as alternative ecological solutions. Once again, whether we consider these changes deleterious or beneficial is a matter of human values, but we must keep in mind that these problems are occurring on a global scale.

Phytoplankton

The amount of UV-B radiation reaching the ocean's surface has long been suspected as a factor influencing primary production. Research shows convincingly that ultraviolet radiation, at levels currently incident at the surface of natural bodies of water, has an influence on phytoplankton productivity (Steemann Nielsen 1964; Jitts et al. 1976; Hobson and Hartley 1983). It has been calculated that, near the surface of the ocean, enhanced UV-B radiation simulating a 25% reduction in ozone concentration would cause a decrease in primary productivity by about 35% (Smith et al. 1980). The estimated reduction in production for the whole euphotic zone would be about 10%.

Effects induced by solar UV-B radiation have been measured to depths of more than 20 m in clear waters and more than 5 m in unclear waters. In marine ecosystems, UV-B radiation penetrates approximately the upper 10% of the marine euphotic zone before it is reduced to 1% of its surface irradiance. Penetration of UV-B radiation into natural waters is a key variable in assessing the potential impact of this radiation on any aquatic ecosystem.

If one assumes that phytoplankton populations sense and control their average vertical position in such a way as to limit UV-B exposure to a tolerable level, then a 10% increase in solar UV-B radiation would necessitate a downward movement of the average position, thereby reducing the average UV-B exposure by 10%. There would be a corresponding reduction of light for photosynthesis. The loss of photosynthetically active radiation in many locations might not be significant. However, in some very productive areas, especially high latitude ocean areas, photosynthetically active radiation is the primary limiting factor for marine productivity (Russell-Hunter 1970). The loss of photosynthetically active radiation from optical measurements has been estimated to be in the range of 2.5 to 5% for a 10% increase in UV-B radiation. If the photosynthetic base of aquatic ecosystems were perturbed one would expect ramifications to extend up through the food web through predator-prey relationships.

Experiments with marine diatoms have shown significant reductions in biomass, protein and chlorophyll at UV-B irradiances equivalent to ozone reductions ranging from 5 to 15 percent. In addition, studies on chain-forming diatoms and other phytoplankton in the laboratory show that increased growth occurs when the UV-B radiation is filtered out of the incident solar radiation, indicating that existing levels of UV-B radiation depress productivity (Thomson et al. 1980; Worrest 1982). Furthermore, indirect effects of ambient levels of UV-B radiation endanger the survival of microorganisms (Euglena, slime mold, some blue-green algae) by decreasing their motility and by inhibiting phototactic and photophobic responses. This reduces the ability of a population to move into favorable environments. This would be a change in response capability that would result in damage of the type that might impair development.

In Hawaii (USA) long-term photoinhibition of growth of six algal species under natural sunlight has been measured (Jokiel and York 1984). Two strains could not grow at all at the levels of irradiance for full natural surface sunlight. Of the species tested, those collected from tropical surface water showed the greatest adaptive power, but it is reasonable to conclude that resistance to solar UV radiation is achieved through expenditure of resources that can be better applied to other needs in less exposed species.

In simulated marine ecosystems enhanced UV-B radiation levels, simulating decreases in ozone of 15 percent, result in shifts of the species diversity and community composition of phytoplankton communities (Worrest et al. 1981). It appears as if in natural communities, a change in species composition rather than a decrease in net production might be a more likely result of an enhanced UV-B exposure. The decreased species diversity observed in simulated field studies is usually not accompanied by deleterious effects on biomass and chlorophyll accumulation, or by deleterious effects on total community primary productivity. However, a change in community composition might result in a more unstable ecosystem and might have influence on higher trophic levels. One effect of enhanced levels of UV-B radiation would be to alter the size distribution of the component producers in a marine ecosystem. Increasing or decreasing the size of the representative primary producers upon which consumers graze can significantly increase the energy allotment required for consumption, thereby reducing the feeding efficiency of the consumer. In addition, the food quality of the producers is altered by exposure to UV-B radiation. It has been demonstrated that the protein content, dry weight, and pigment concentration are all depressed by enhanced levels of UV-B radiation.

Zooplankton

Zooplankton are critical components in typical aquatic food webs (nutrient pathways) that lead to larger animals, including those comprising commercial fisheries (finfish and shellfish) and therefore man himself. With respect to potential impacts of enhanced solar UV-B radiation, only the zooplankton living in daylight in the upper several meters would be directly affected. Many zooplankton species normally live very close to the surface, even in daylight, while others occupy the near-surface layer during only part of their life cycle.

The near-surface layer is a very important zone in the interactions of the physical/chemical/biological components of aquatic systems. Zooplankton have apparently evolved mechanisms and behavior by which they have adjusted to current levels of UV radiation (Damkaer 1982), but they may not be able to adjust to relatively rapid increases in solar UV radiation. If there were changes in abundance of zooplankton species, those changes would have an impact far beyond any direct effects because of the critical role of zooplankton in energy transfer within the ecosystem.

Karanas et al. (1979, 1981) presented evidence that acute exposure of a marine invertebrate zooplankton resulted in reduced survival of the organisms. They also showed that exposure of this species to sublethal exposures of UV-B radiation could also reduce the fecundity of the parents. Thomson (1986) demonstrated that current levels of UV-B radiation are of significance in the developmental life of several species of shellfish. For some species a 10% decrease in column ozone could lead to as much as an 18% increase in the number of abnormal larvae produced.

Regardless of the cellular-level responses to UV irradiation, it is usually noted that up to some level of UV exposure there is no apparent effect on the organism (Damkaer et al. 1980: Damkaer and Dey 1982). At greater doses either the repair systems themselves may have become inactivated by the radiation, or the damage to the general tissues is beyond the capacity of the repair systems (Damkaer and Dey 1983). To be effective, these threshold levels probably must be exceeded during several consecutive days. The apparent UV thresholds are near current incident UV levels. The thresholds for all groups in one test appeared to be above the present median solar incident UV levels at the test location, at least until late in the time span of natural occurrence near the surface. This season could be significantly shortened by a 20% ozone reduction. Whether or not the populations could endure with a drastically reduced time of near-surface occurrence is not known. Success of any year-class depends on the timing of a great number of other events in addition to levels of exposure to UV-B radiation (Hunter et al. 1982).

Hunter et al. (1982) exposed anchovy eggs and larvae and mackeral larvae to high doses of UV-B radiation in small closed containers. These authors provided data that indicated that anchovy larvae off southern California are typically centered in moderately productive ocean water having about 0.5 mg Chl $\underline{a}$ m^{-3}. Baker et al. (1981)

calculated surface DNA-effective UV-B irradiance levels expected for this area, and Smith and Baker (1979) calculated the penetration of UV-B radiation into the moderately productive ocean water. An analysis by Damkaer indicates that 14.7% of the anchovy larvae would die in 4 to 10 days if there were no vertical mixing of the larvae. These static situations no doubt approach "worst case" scenarios. However, static situations are not probable because of physical vertical mixing of water (through the action of wind, density currents, and tides) and the active and passive movement of fish larvae. If some vertical mixing did not offer relief from the effects of UV-B radiation, it is likely that there would be no anchovy larvae above a few meters depth: this is clearly not the case. Probably the surface mixed layer extends to at least 25 m from December to February (Sverdrup et al. 1942). A mixed layer of at least 10 m can be assumed for the rest of the year.

For the mixed situation in February, the larvae would spend less than one hour each day in the surface 1-m layer, resulting in exposures where the threshold doses would never be reached in the larval stage. In the February model, with mixing to 25 m, there would have to be a six-fold increase in incident UV-B radiation before threshold doses would be reached. For the months March-October, with mixing to 10 m, the threshold doses are also not reached within the 20 days available before the larvae become vertically migrating. Only in April and August, with the highest surface irradiances, are these doses approached within this available time (ca. 22 days).

For March-October, with 10-m mixing, a 20% increase in incident UV-B radiation (a result of about a 9% decrease in the atmospheric ozone column) would cause the depth of the threshold dose-rate to be increased. With the 20% increase in incident irradiance, for the dose/dose-rate threshold model, all of the anchovy larvae within the 10-m mixed layer in April and August would be killed, the threshold doses being achieved after 15 days.

Apparently at all months about 36% of the larval anchovy population is above 10 m (Hunter et al. 1981). The greatest numbers of anchovy larvae are found in April (20% of annual population), so that 7.2% of the annual population would be eliminated with a 9% ozone decrease. Only 1.9% of the annual population is present in August, so the loss of those above 10 m would amount to 0.7% of the annual population. The total predicted loss, then, due to a 9% decrease in total ozone column, would be about 8% of the larval anchovy population.

Because of complex interactions between mixing-depths, vertical distribution of larval anchovy, seasonal changes in solar irradiance and the penetration of UV radiation into seawater, and seasonal changes in anchovy abundance, there is not a linear relationship between mixing-depth and predicted annual loss of anchovy larvae.

In addition to the direct effects upon the fisheries, it is possible that with less primary production of organic biomass there would also be an increased mortality in larval fish due to food limitation. And perhaps there would be a synergistic effect on mortality in that some animals die from direct exposure, some die from lack of food, and some die from the combination of a reduction in food and the weakening from exposure (or are weakened and become outcompeted by other fauna for limited food reserves).

The impact on marine fisheries as a food supply to humans would be significant if the species of phyto- and zooplankton that adapted to enhanced levels of UV-B radiation were of different nutritional value (if they altered growth and reproductive capacity of the consumers). If the indirect impact of suppression upon consumers were linear, a 5% reduction of primary production would result in a 5% reduction in fish production. A question still under investigation is whether the relationships between producers and consumers might be nonlinear. For example, there may be an amplification factor involved that results in a relatively greater impact at higher trophic levels than at the primary-producer level. As illustrated in Table 3, a 5% reduction in primary production (P_1) would give an annual yield of 115×10^9 kg of fish flesh (a 5% reduction): whereas a 5% reduction in the ecological efficiency of energy transfer (e) would yield 103×10^9 kg of fish flesh (a 14% reduction).

Table 3. Annual fish production in coastal waters. Baseline data for coastal waters adapted from Ryther (1969).

	Baseline	-5% P_1	-5% e
Primary production, kJ m^{-2} yr^{-1}, (P_1)	4200	4000	4200
Ecological efficiency per trophic level, (e)	0.15	0.15	0.14
Number of trophic levels from plant production to fish production, (n)	3	3	3
Fish production, kJ m^{-2} yr^{-1}, ($P_1 e^n$)	14	13	12
Total fish production, 10^9 kg yr^{-1} (using Winberg's transformation, 4.2 kJ = 1 g fish flesh)	121	115	103
Percentage of baseline fish production	(100%)	(95%)	(86%)

Potential Consequences to World Fisheries

Well over 95% of the sea's living resources occur within belts of ocean 200-miles wide surrounding the coastal nations of the world. By international agreement each nation exercises economic jurisdiction over these Extended Economic Zones (EEZ's). With the establishment of the 200-mile EEZ's, the coastal nations of the world have acquired an area of sea surface amounting to about 25% of the globe. More than 99% of the global catch of marine fisheries is currently taken within the EEZ's. These fish are of crucial importance in world nutrition, making up about 18% of the average world animal protein intake. That figure rises to nearly 40% in Asia where more than half of mankind lives. The people of Japan, for instance, derive about 60% of their intake of animal protein from the ocean (Clark 1981). The annual income to the world's fishermen from marine catches is roughly US$10 billion, with a world fish catch of about 70 million metric tons.

The Peruvian anchoveta fishery is an example of the economic impact resulting from a stress on a fishery. The fishery developed in the 1960's into the world's largest single fishery. In 1970, Peru's anchovy harvest amounted to 12.3 million metric tons, or more than 20% of the total world marine finfish catch for that year. These fish rely on phytoplankton blooms that result from the surfacing of colder nutrient-rich water. In 1972, the Peruvian catch plummeted to 4 million metric tons and fell further in 1973 to 1.8 million metric tons. The primary cause of this drastic collapse was the occurrence of an El Nino, although heavy fishing aggravated the situation (Bardach and Santerre 1981). The economic consequences to the fishery were catastrophic. The major use of the anchoveta harvest was for the production of fishmeal, which was used as a major source of bulk protein in livestock feed. A shortfall of the fishmeal in the world's markets had severe ripple effects on other animal feeds and on livestock prices. The price of fishmeal rose 127%, the price of soybean meal rose 99%, and the cost of pork, for example, rose 96%--all in real dollar values. Since the export of anchoveta fishmeal constituted Peru's second largest source of foreign exchange, the loss of the fishery had a major influence on the Peruvian economy.

The recovery of a depleted fishery population may require many years, even if catches are prohibited in the meanwhile. Economic survival of the existing resource industry may, however, depend upon continuing catches, even though these will delay rebuilding of the stock and perhaps increase the probability of the population's collapse.

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CURRENT UNDERSTANDING OF THE EFFECTS OF INCREASED LEVELS OF SOLAR ULTRAVIOLET-B RADIATION TO CROPS AND NATURAL PLANT ECOSYSTEMS

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SUMMARY OF KEY FINDINGS:

1. **PLANTS HAVE NATURAL ADAPTATIONS TO UV RADIATION.**

   1a. These include specific repair mechanisms, mechanisms to minimize damage, and protective mechanisms.

   1b. Despite these natural adaptations, many plants are still adversely affected by increased levels of UV radiation.

2. **TO DATE, OVER 200 PLANT SPECIES AND CULTIVARS HAVE BEEN SCREENED FOR UV SENSITIVITY.**

   2a. Alarmingly, two out of every three showed some degree of sensitivity.

   2b. Commonly observed effects include plant stunting, reduction in leaf area and total dry matter production, chlorosis, and reduced physiological vigor.

3. **OVER 90% OF OUR KNOWLEDGE OF UV-B EFFECTS STEMS FROM STUDIES ON CROP PLANTS, WHICH ACCOUNT FOR LESS THAN 10% OF TOTAL GLOBAL PRODUCTIVITY.**

   3a. Although natural vegetation (forests, grasslands, shrublands, etc.) account for over 90% of global productivity, little or no information exists for trees, woody shrubs, vines or lower plants.

   3b. Preliminary data suggest that UV-B changes may pose a risk to forests.

   3c. The effects of UV radiation have been examined in representatives of only four of the ten major terrestrial ecosystems and for only a third of the plant growth forms.

   3d. Therefore, to assess the effects of UV-B change on a truely global basis, one would have to make the unlikely assumption that natural terrestrial ecosystems respond in an analogous fashion to herbaceous agricultural species.

4. **DESPITE THE LARGE UNCERTAINTIES, THE OVERRIDING TREND IN THE EXPERIMENTAL DATA SUGGESTS A POTENTIAL REDUCTION IN CROP YIELD DUE TO INCREASED UV-B RADIATION.**

    4a. Increased levels of UV-B simulating a 25% ozone depletion resulted in crop yield reductions of up to 25% in a 5-year field study on soybean.

    4b. Unlike drought or other geographically restricted stresses, increases in UV-B would affect all areas of the world simultaneously. Even small reductions in crop yield on a global basis could lead to considerable economic consequences.

5. **OF CROP CULTIVARS TESTED, APPROXIMATELY 70% WERE SENSITIVE TO UV-B; THE REMAINING 30% WERE GENERALLY NOT AFFECTED.**

    5a. This suggests that UV-B tolerant genotypes exist.

    5b. Selective breeding for resistance to UV-B may be useful in reducing the impact of increased UV-B radiation if it does not produce deleterious effects for other characteristics desired in plants. Presently, the genetic bases for these differences between sensitive and insensitive plants are not well understood.

6. **CROP QUALITY MAY BE ALTERED BY INCREASES IN UV-B.**

    6a. The oil and protein content of soybean seed was reduced up to 10%.

    6b. Crop quality changes have also been reported in tomato, potato, and sugar beet, although not always in a detrimental direction.

7. **THE EFFECTS OF UV-B ON DISEASE OR PEST ATTACK VARY WITH PATHOGEN, PLANT SPECIES, AND CULTIVAR.**

    7a. Reduced vigor in UV-sensitive plants could render the plants more susceptible to pest or disease damage and thus result in additional reductions in crop yield.

    7b. No studies have been specifically designed to examine the effects of UV-B on pathogens therefore our knowledge is very limited.

8. **INTERACTIONS BETWEEN UV-B RADIATION AND OTHER ENVIRONMENTAL FACTORS ARE IMPORTANT IN DETERMINING POTENTIAL UV-B EFFECTS ON PLANTS.**

    8a. UV-B effects tend to be exaggerated under low light regimes and masked under conditions of nutrient or water stress.

    8b. Interactions with other environmental factors make extrapolation of data obtained from growth chambers or greenhouses to field conditions difficult and often unreliable.

9. **CHANGES IN UV-B LEVELS MAY INDUCE SHIFTS IN THE COMPETITIVE BALANCE AMONG SPECIES, POTENTIALLY ALTERING AGRICULTURAL AND NATURAL ECOSYSTEMS.**

    9A. If these shifts favor weeds over crops, increases in UV-B radiation could have severe consequences, such as the economic cost of increased tilling and herbicide application.

    9b. Since competition also exists in natural ecosystems, increases in UV-B could alter the composition of natural ecosystems by favoring UV tolerant plants and eliminating UV sensitive ones.

INTRODUCTION

This document examines the published and unpublished material currently available to assess the likely impact of projected increases in UV-B radiation upon global crop productivity and the distribution and abundance of plants in natural ecosystems. The limitations to this assessment are formidable because of the paucity of experimental data and the slow development of appropriate experimental technology. Ideally, experiments should be designed to develop a data base which perfectly simulates future conditions for all plant species. These conditions should include all direct effects of increases in UV-B in addition to all of the possible significant combinations with other effects (interactions). Such interactions should include, but not be limited to, the effects of increased atmospheric levels of carbon dioxide (CO_2), drought, mineral deficiency, etc. Unfortunately, such ideal circumstances do not exist. Therefore, the existing data base for this assessment will only permit an examination of some of the potential effects of UV-B changes. In the absence of more detailed scientific information, the data presented here may serve to warn us of the potential consequences of ozone depletions. The magnitude of these changes are as of yet uncertain.

NATURAL PLANT ADAPTATIONS TO UV

To date, over 200 species of plants or cultivars have been screened for UV sensitivity and tremendous variability exists (Krizek 1978; Van, Garrard, and West 1976; Hashimoto and Tajima 1980; Tevini, Iwanzik, and Thoma 1981 and 1982; Tevini and Iwanzik 1982; Teramura 1983). Alarmingly, over two-thirds of these show deleterious effects of UV-B radiation exposure. Commonly observed effects include reductions in leaf area, stunting, reductions in dry matter accumulation, and chlorosis (loss of pigmentation). Some plants even show sensitivity to ambient levels of UV-B radiation (Teramura, Biggs, and Kossuth 1980; Bogenrieder and Klein 1978; Sisson and Caldwell 1976) while others are apparently unaffected by rather massive UV increases (Becwar, Moore, and Burke 1982; Ambler, Rowland, and Maher 1978). Similarly, large differences have been reported among cultivars of a given species (Biggs, Kossuth, and Teramura 1981; Dumpert and Boscher 1982; Murali and Teramura 1986a, b; Murali, Teramura, and Randall 1986). Presently the mechanisms for these inherent differences are not well-understood.

Three main categories of natural UV protective mechanisms may be considered (Beggs, Schneider-Ziebert, and Wellmann 1986). The first includes repair mechanisms such as photoreactivation, a light-activated, enzyme-mediated process whereby pyrimidine dimmers produced by UV absorption are split (Rupert 1984). Indirect evidence (Beggs, Schneider-Ziebert, and Wellmann 1986; Tanada and Hendricks 1953; Bridge and Klarman 1973) suggests that photoreactivation is a widespread phenomenon in plants. Excision repair, the replacement of deleterious photoproducts by new, correct DNA sequences, has also been documented in plant tissues (Howland, Hart, and Yette 1975, Soyfer 1983). Finally, quenching and free radical scavenging of oxygen singlets produced by photo-oxidation also alleviate some types of UV-induced damage.

The second category of protective mechanisms include those that tend to minimize the damaging effects of UV-B radiation. Probably the most important of these mechanisms in plants is growth delay. If cell division stops or is slowed upon UV irradiation, other repair mechanisms such as the ones mentioned above could help ameliorate the damage before it becomes lethal. Although many plants show a growth inhibition upon UV-B radiation exposure (Teramura 1983), it is not clear whether this inhibition is the direct effect of the damage or due to this protective mechanism.

The third category of protective mechanisms involves those which effectively reduce the amount of UV radiation actually reaching sensitive plant targets. Structural attenuation by the cuticle and cell wall may play only a minor role since they offer little UV absorption (Caldwell, Robberecht, and Flint 1983; Steinmuller and Tevini 1985). The principal mechanism is probably the production of UV-absorbing pigments in outer tissue layers. Flavonoids and other related polyphenolic compounds, which occur in epidermal cells and strongly absorb UV radiation (Caldwell, Robberecht, and Flint 1983), are likely candidates. It has been shown that flavonoid concentrations in plant leaves substantially increase upon UV exposure (Wellman 1982; Murali and Teramura 1985a and 1986a; Robberecht and Caldwell 1978; Tevini, Iwanzik, and Teramura 1981 and 1983; Flint, Jordan, and Caldwell 1985). Some studies suggest that despite large increases in flavonoid concentration, metabolic processes, such as photosynthesis, are still adversely affected (Sisson 1981, Teramura et al. 1984, Mirecki and Teramura 1984). Also, differences in total leaf flavonoid concentrations alone do not account for the range of responses observed in species sensitivity. For example, total leaf flavonoid levels found in UV-B irradiated soybeans were less than those found in cucumber, yet cucumber is much more sensitive to UV (Murali and Teramura 1986a, c). Therefore, species sensitivity to UV-B radiation is probably the product of a number of mechanisms acting in concert within the plant. We urgently need more specific information concerning plant adaptations to UV-B radiation before we can further refine our estimates of the ability of natural plant protective mechanisms to compensate for the projected increases in solar UV-B radiation. Without such a mechanistic understanding, we must continue to screen large numbers of diverse species of plants for UV sensitivity.

EXTRAPOLATION FROM CONTROLLED ENVIRONMENTS TO THE FIELD

Plant responses in growth chambers or greenhouses may neither quantitatively nor qualitatively resemble field responses because the environments within them are unlike those found in nature. Plants are more sensitive to a given UV dose when grown in growth chambers compared with field-grown plants (Caldwell 1981, Bennett 1981, Teramura 1982, Mirecki and Teramura 1984) because in artificial environments a single factor is generally manipulated, while all other factors are kept constant or are optimized for growth. Plants outdoors commonly experience simultaneous, multiple stresses including water or nutrient limitation. In addition to these differences in physical factors, artificial environments lack biotic factors such as the interactions between other plants, insects, diseases, etc.

However, enormous complexities are inherent in field studies. Daily changes in the environment are superimposed upon longer scale seasonal and annual changes. Both temporal and spatial variability often result in inconsistencies in plant responses between one year and the next (for examples see Biggs et al. 1984; Gold and Caldwell 1983; Teramura 1981b; Lydon, Teramura, and Summers 1986).

Therefore, one useful approach in understanding the effects of UV-B radiation on plants has been the study of the interactions between UV and other, commonly experienced plant stresses. For instance, these studies revealed that previous exposure to water stress may affect the susceptibility of some plants to UV, by inducing flavonoid biosynthesis (Teramura, Tevini, and Iwanzik 1983; Tevini, Thoma, and Iwanzik 1983; Teramura et al. 1984a; Teramura, Forseth, and Lydon 1984). The results of field experiments (Murali and Teramura 1986c) revealed no additional deleterious effects of UV-B radiation when combined with water stress. It was hypothesized that changes in leaf anatomy, increased flavonoid production, and reduced growth induced by water stress masked the UV effects.

In some cases, plant productivity (accumulation of dry matter) became more sensitive to UV-B radiation as total mineral supply decreased (Bogenrieder and Doute 1982). In others, however, (Murali and Teramura 1985a, b) plant sensitivity to UV-B radiation decreased as the phosphorus level decreased. This suggests that the greatest impact of increases in UV-B might appear in well-fertilized (agricultural) regions, rather than in areas of low fertility, where productivity is already limited.

In most growth chambers, visible irradiances range from 10 to 40% of average midday irradiances. This is a cause for concern, since many of the deleterious effects of UV radiation may be ameliorated by exposures to longer wavelength visible radiation. Therefore, growth chamber experiments tend to overestimate the impact of UV effectiveness in the field. Despite the wide range of plant species and growth conditions, a clear trend emerges: plants grown in higher levels of visible radiation are less sensitive to UV-B radiation. A corollary to this conclusion is that plant sensitivity to UV-B radiation is strongly influenced by the level of visible radiation available during growth and development, and that shaded environments maximize this sensitivity.

Lydon, Teramura, and Summers (1986) and Teramura and Murali (1986) have specifically examined the differences in UV-B radiation response between field and greehouse-grown soybean. Six soybean cultivars were grown in an unshaded greenhouse and in the field under a similar UV regime. Cultivar sensitivity was ranked based upon a combined plant response including changes in total plant dry weight, leaf area, and plant height. The relative ranking for UV-B sensitivity in the greenhouse was qualitatively quite similar to that found in the field. The major difference was that UV-B radiation produced a substantially larger (2- to 10-fold) effect on greenhouse plants compared with field-grown plants. Also, in specific instances, different conclusions could be drawn from the individual data sets. For example, cultivar James was sensitive and York resistant to UV-B based upon greenhouse data. In the field, however, these cultivars demonstrated the opposite response. Therefore, if growth chamber-to-field extrapolations are necessary, they must be done with the utmost caution. At best, general trends may be implied, but specific or quantitative extrapolations do not yet seem plausible.

Despite a great range of experimental growth conditions and UV doses, many cultivars show large individual variation in response to UV-B radiation (Exhibit 11-1). Therefore, the potential for ameliorating the impacts of projected increases in solar UV radiation may be present in our current crop germplasm by genetically selecting for UV tolerance. However, we have little understanding of the mechanisms responsible for these cultivar differences and the relationship between genetic factors that provide UV tolerance to other desirable plant characteristics. If tolerance to UV-B radiation were linked (in a genetic sense) to some undesirable characteristics such as drought susceptibility, crop breeding may not ameliorate the impacts of UV-B damage.

UV-B EFFECTS ON NATURAL ECOSYSTEMS AND PLANT GROWTH FORMS

Most of our knowledge of the biological effects of increasing solar UV radiation stems from research focused upon agricultural crops. Plants from only four of the ten major ecosystems, representing only about 27% of global net primary productivity (NPP) have been examined (Exhibit 11-2). In temperate forests and temperate grasslands, only very limited preliminary data are available. In one such preliminary study, Sullivan and Teramura (unpublished) found that red, lodgepole, and loblolly pine seedlings were adversely affected by UV-B radiation after only 4-12 weeks of exposure. Therefore our forests are also potentially at risk by

EXHIBIT 11-1

A Summary of Studies Examining Cultivars Differences in UV-B Radiation Sensitivity

Crop	Number of Cultivars	Growth Condition a/	Conclusion b/	Basis of Comparison c/	Reference
Glycine max	19	G.C.	20% tolerant 60% intermediate 20% sensitive	d.w.	Biggs et al. 1981
	2	G.H.	Cultivar Altona more sensitive than Bragg	d.w.	Vu et al. 1978
	23	G.H.	8% tolerant 33% unaffected 59% sensitive	d.w.	Teramura and Murali 1986
	5	F	20% sensitive 80% unaffected	seed d.w.	
Phaseolus vulgaris	2	G.H. & G.C.	88t 290 more sensitive than Astro	leaf resistance	Bennett (1981)
	3	G.H.	Maxidor sensitiv Saxa, Favorit tolerant		Dumpert and Boscher (1982)
Brassica oleracea	2	G.H. & G.C.	no difference	p.s. & d.w.	Van et al. (1976)
	2	G.C.	(?)		Garrard et al. (1976)
Cucumis sativus	5	G.H.	20% tolerant 80% sensitive	d.w.	Murali and Teramura (1986a)
	2	G.H.	Poinsett extremely sensitive, Ashley slightly sensitive	d.w.	Krizek (1978)
Tritium aestivum	4	G.H.	no difference (?)	d.w.	Dumpert and Boscher (1982)
	7	G.C.	no difference	d.w.	Biggs and Kossuth (1978)
	2	F	no difference	d.w.	Biggs et al. (1984)
Zea mays	4	G.C.	25% extremely sensitive 75% sensitive	d.w.	Biggs and Kossuth (1978)
Oryza sativa	5	G.C.	60% tolerant 40% sensitive	d.w.	Biggs and Kossuth (1978)
Hordeum vulgare	4	G.H.	25% tolerant 75% sensitive	d.w.	Dumpert and Boscher (1982)
	3	G.C.	no difference	d.w.	Biggs and Kossuth (1978)
Spinacia oleracea	2	G.H.	both sensitive	d.w.	Dumpert and Boscher (1982)

EXHIBIT 11-1

A Summary of Studies Examining Cultivars Differences in UV-B Radiation Sensitivity
(continued)

Crop	Number of Cultivars	Growth Condition a/	Conclusion b/	Basis of Comparison c/	Reference
Gossypium hirsutum	2	G.H.	no difference	d.w.	Ambler et al. (1978)
Pennisetum glaucum	2	G.C.	no difference	d.w.	Biggs and Kossuth (1978)
Cucurbita pepo	3	G.C.	no difference	d.w.	Biggs and Kossuth (1978)

a/ G.H. = greenhouse; G.C. = growth chamber; F = field

b/ If data presented, sensitive means UV-B radiation reduced d.w. by at least 10% over control plants. Tolerant indicates that UV-B resulted in less than 10% reduction in growth. In some cases, tolerant plants were even stimulated by UV-B radiation.

c/ d.w. = total plant dry wt; p.s. = net photosynthesis.

EXHIBIT 11-2

Survey of UV Studies by Major Terrestrial Plant Ecosystems (after Whittaker 1975)

Ecosystem	Global NPP (10^9 ton/yr)	Total Area (10^6 km^2)	Included in UV Study[a]
Tropical forest	49.4	24.5	no
Temperate forest	14.9	12.0	yes
Savanna	13.5	15.0	no
Boreal forest	9.6	12.0	no
Agricultural	9.1	14.0	yes
Woodland and scrubland	6.0	8.5	no
Temperate grassland	5.4	9.0	yes
Swamp and marsh	4.0	2.0	no
Desert and semidesert	1.7	42.0	no
Tundra and alpine	1.1	8.0	yes

[a] Only studies examining some aspect of growth.

changes in UV-B radiation. Of 25 categories of major plant growth forms, the effectiveness of UV-B radiation has only been examined in eight (32%). Only very limited data exist for trees, vines, small woody shrubs, epiphytes, or lower vascular plants. Thus the experimental data base represents only 19 of the 314 plant families in the world (Cronquist 1981). Of those families tested, only seven include representive species in which harvestable yield was examined. Therefore, we have very little information from which to predict the potential impacts of increasing levels of solar UV radiation on global terrestrial productivity or on natural ecosystem dynamics.

Ecosystem composition and function are dependent upon the influence of numerous biotic and abiotic factors. Within populations, plants may possess protective mechanisms to UV-B, but the ability of higher plants to adapt within the timeframe of expected changes in UV-B radiation is unclear. Differential sensitivity could result in subtle shifts in species interactions such as competition. These shifts as well as changes in abiotic factors (precipitation patterns, temperature, etc.) could produce significant changes in the abundance and distribution of natural vegetation and ecosystem composition.

EFFECTS IN A HIGHER AMBIENT CO_2 ENVIRONMENT AND IN COMBINATION WITH OTHER ATMOSPHERIC POLLUTANTS

Global atmospheric carbon dioxide (CO_2) concentration has been gradually increasing from 205 ppm some 20,000 years ago to approximately 340 ppm today (Keelings 1978, Nefter et al. 1982). It is anticipated that sometime between 2075 and 2100, the atmospheric CO_2 concentration will reach 600 ppm (Gates 1983).

At present we have no direct experimental evidence on the effects of UV-B radiation under increased levels of atmospheric CO_2. In general CO_2 enrichment increases photosynthesis and water use efficiency in most plants (which are reduced by UV-B radiation). Exhibit 11-3 compares the general effects of CO_2 enrichment with increased UV-B radiation.

Recently, however, some confounding evidence has been found for perennials, in which high levels of CO_2 led to a decrease in biomass production (Fried, 1986). Furthermore, most CO_2 work has been done in growth chambers, which differs from realistic field conditions. Therefore, the net effect of an interaction between UV-B radiation and CO_2 enrichment cannot, at this time, be predicted. Whether the deleterious effects of UV-B will be proportionally higher or lower in a high CO_2 environment is uncertain. Similarly, the combined impacts of higher CO_2 and UV-B on inter- and intraspecific competitive balance is impossible to ascertain. Other changes in the environment, such as those due to global warming and climatic changes, may also play important roles, but cannot be assessed at this time. Further uncertainty stems from the absence of knowledge on the interactions between increased UV-B levels and that of other

EXHIBIT 11-3

Summary of UV-B and CO2 Effects on Plants
(Lemon 1983; Teramura 1983)

Plant Characteristic	Enhanced UV-B	Doubling of CO2
Photosynthesis	Decreases in many C3 and C4 plants	In C3 plants increases up to 100% but in C4 plant only a small increase
Leaf conductance	No effect in many plants	Decreases both in C3 and C4 plants
Water use efficiency	Decreases in most plants	Increases in both C3 and C4 plants
Dry matter production and yield	Decreases in many plants	In C3 plants almost doubles but in C4 plants only a small increase
Leaf area	Decreases in many plants	Increases more in C3 than C4 plants
Specific leaf weight	Increases in many plants	Increases
Crop maturity	No effect	Accelerated
Flowering	May inhibit or stimulate flowering in some plants	Flowers produced earlier
Interspecific differences	Species may vary in degree of response	Major differences occur between C3 and C4 plants
Intraspecific differences	Response varies among cultivars	Response may vary among cultivars
Drought stress	Plants become less sensitive to UV-B but not tolerant to drought	Plants become more drought tolerant

pollutants in the lower atmosphere. Primarily anthropogenic in origin, the major pollutants include ozone, sulfur oxides, and nitrogen oxides. Acccording to the National Crop Loss Assessment Network, farm crop losses in the United States in 1981 due to tropospheric air pollution were between 1 and 2 billion dollars. Many studies have demonstrated that in combination, the deleterious effects of air pollutants were additive and in a few cases multiplicative (Reinert, Heagle, and Heck 1975). At present, no data are available on the interaction between UV-B radiation and these various air pollutants.

RISKS TO CROP YIELD

Due to their relatively high costs and increased technical difficulty, during the past 10 years only nine field studies have examined the effects of UV-B radiation on crop yield (Exhibits 11-4 and 11-5). These nine studies included 22 crop species. Corn (*Zea mays*) was included in six of the nine studies, soybean (*Glycine max*) found in four, and tomato (*Lycopersicon esculentum*), bean (*Phaseolus vulgaris*), and potato (*Solanum tuberosum*) were each found in three studies. Yield was reduced by UV-B in about half of these species.

Ambler, Rowland, and Maher (1978) grew eight species of crops in a field at Beltsville, Maryland (39°N). Plants were grown under a lamp irradiation system maintained 1.6 m above them in a linear arrangement of unfiltered Westinghouse BZS-CLC and FS-40 sunlamps. A 2-dimensional gradient was established: one parallel to the lamps and another at right angles. Only broccoli showed a significant UV effect although the authors suggested that sorghum and corn also were affected.

Bartholic, Halsey, and Garrard (1975) conducted field exclusion studies in Gainesville, Florida (29° 36'N) in which ambient UV-B was filtered by plastic films . Since plants were grown under panels covered with these films, only the direct beam component of ambient UV was removed (approximately one-half the total ambient UV present). Compared with uncovered plots, total yield decreased in beans and corn growing under the UV absorbing panels. Furthermore, tomato matured significantly earlier, resulting in an apparent decrease in fruit weight in plants growing in uncovered plots.

Becwar, Moore, and Burke (1982) also conducted an exclusion study located at 3000 m in the Colorado Rocky Mountains (39° 11'N). The only UV effect reported was a decrease in wheat height (between 8 and 19% depending upon plant age), with no corresponding change in total plant dry weight. A second study was conducted using filtered FS-40 sunlamps to supplement ambient levels of solar UV-B. No significant reduction in crop yield was observed despite a calculated 52% UV increase.

EXHIBIT 11-4

Summary of Field Studies Examining the Effects of UV-B Radiation on Crop Yields.
Values represent percent changes from controls

	Ambler et al. (1978) (1)	Bartholic et al. (1975) (2)	Becwar et al. (1982) (3)	Biggs and Kossuth (1978) (4)	Biggs et al. (1984) (4)	Eisenstark et al. (1985) (4)	Esser (1980) (5)	Hart et al. (1975) (1)
Cucurbita maxima	0							
Cucurbita pepo				-14 to -90				
Phaseolus vulgaris	0	+12 to +15					+53 to -75	
Triticum aestivum					-5			
Zea mays	0	+29 to +39		0	0	-79 to -87		0
Spinacia oleracea							+11 to -56	
Sorghum bicolor	0							
Capsicum annum								-(?)
Glycine max	0							0
Cynodon dactylon								
Beta vulgaris	0							
Brassica oleracea var. capitata							+19 to -49	
Brassica oleracea var. botrytis	-24 to -45%							
Lycopersicon esculentum		-5 to -26		-11 to -39				0
Nicotiana tobaccum								0
Raphanus sativus			0					
Pennisetum glaucum								0
Solanum tuberosum			0	0			-2 to -41	
Brassica juncea				-9 to -43				
Vigna unguiculata				-18 to -36				
Oryza sativa					0			
Arachis hypogaea				0				0

(1) Unfiltered Westinghouse BZS-CLG and FS-40 sunlamps
(2) Ambient UV filtered with Mylar Type S or poleyethylene
(3) Ambient UV filtered with cellulose acetate, Aclar or Mylar
(4) Westinghouses FS-40 sunlamps filtered with cellulose acetate or Mylar
(5) Unfiltered Philips TL 40/12 sunlamps and lamps filtered with Schott WG 305 (2 and 3 mm) filters

Biggs and Kossuth (1978) reported yields for seven crops grown in beds filled with a synthetic soil mix in Gainesville, Florida (29° 36'). UV-B radiation was supplemented with a linear arrangement of six FS-40 sunlamps placed at a 12° angle from horizontal, producing a gradient in UV-B irradiances. The greatest reductions in yield were often found in plants receiving the lowest UV irradiance and the largest UV effects were found in plants growing adjacent to ones showing little or no effect. To date, we have no explanation for these observations.

In another field experiment, Biggs et al. (1984) conducted a two-year evaluation of crop yield in rice, wheat, corn and soybean. Plants were again grown in beds filled with synthetic soils, and UV irradiation was supplied by filtered FS-40 sunlamps providing 0, 32, 23, or 16% UV enhancements. The only significant yield reduction reported was for wheat (5% reduction) and only for one of the two experimental years. The data for rice, corn and soybean were highly variable and no statistical differences could be detected.

Eisenstark et al. (1985) grew corn in large pots for three growing seasons in Columbia, Missouri (38° 57'N). Two levels of UV radiation were supplied by filtered FS-40 sunlamps simulating a 7 and 21% ozone depletion. Controls included filtered lamps and no overhead lamps. Plants were found to be particularly susceptible to UV-induced effects during tassel development (Eisenstark and Perrot, 1985). Plants irradiated as seedlings produced total grain yield reductions of 23 and 32% respectively when these plants were compared with controls. Even larger differences were found when these plants were compared with those grown without overhead lamps. As yet, the reasons for this discrepency are unknown.

Esser (1980) conducted field studies in Frankfurt, Federal Republic of Germany (50°N) on bean, cabbage, spinach, and potato. He used linearly arranged Philips TL40/12 sunlamps suspended 3 m above the plants producing four UV irradiances using a combination of reflectors, Schott WG305 filters, and unfiltered lamps. Significant yield reductions were found only under unfiltered lamps in the four crops tested. Yields for spinach, cabbage, and bean increased under filtered lamps.

Hart et al. (1975) grew plants under linearly arranged unfiltered FS-40 sunlamps at Beltsville, Maryland (39°N). The absence of experimental data and details on this study limit its usefulness.

Teramura has grown soybeans for five seasons at Beltsville, Maryland (39°N) (Exhibit 11-5). During the first two years, six soybean cultivars were grown, but only two cultivars grown in subsequent years under filtered FS-40 sunlamps. Field experiments simulated 0, 16, and 25% ozone depletions. Seed yield was consistently reduced at a simulated 25% ozone depletion in cultivar Essex. Yield reductions of 20-25% were reported in three of the

EXHIBIT II-5

Details of Field Study by Teramura (1981-1985) a/

CULTIVAR b/	YEAR: SIMULATED OZONE CHANGE (%):	1981		1982		1983 c/		1984 c/		1985	
		-16	-25	-16	-25	-16	-25	-16	-25	-16	-25
Bay		-10	NE d/	+6	-8						
Essex		-25 e/	NE	-12	-23	+39 e/	+6 e/	+14 e/	-7	+6	-20 e/
James		-14 e/	NE	-22	-25						
Williams		+22 e/	NE	+9	+14	+13 e/	-11 e/	+15 e/	+10 e/	+18 e/	+4 e
York		-12	NE	-25 e/	-8						
Forrest		NE	NE	-14	+27						

a/ Values reported are percent changes in seed yields for given simulated ozone changes (-16% and -25%) compared to controls (yields measured on a dry weight basis). Irradiance by either mylar (control) or cellulose acetate (UV-B supplemented) filtered FS-40.

b/ After initially screening 23 cultivars (16 of which were sensitive to UV-B; >10% yield reduction) in the greenhouse, these six were chosen for field experimentation. The six represent the full range of UV sensitivity found in the greenhouse; including very sensitive and very tolerant cultivars. Beginning in 1983 only Essex (very sensitive) and Williams (very tolerant) were planted in the field to increase the experimental sample size to 200. As shown in the table, yields for Essex were generally reduced at the higher UV level (ozone change of -25%), but were mixed (relative to controls) at the other UV level. Yields for Williams were generally enhanced by increased UV. Of note is that Essex is currently replacing other older cultivars (including Williams) and is becoming one of the most widely planned soybeans in the U.S. In a UV enriched environment, Essex will be deleteriously affected. Therefore superior cultivars being developed today by crop breeders may not be suitable for the future should the UV environment change.

c/ Drought year. Low yields for both controls and experimental (i.e., dosed) plants.

d/ NE - Not evaluated.

e/ Significantly different at p 0.05 level.

five years. The "UV-tolerant" cultivar Williams actually showed slight increases in yield in all years except 1983, when an 11% reduction in yield was observed. Also in 1983, a substantially higher relative yield (6% increase) was found in cultivar Essex, which was opposite to that observed in the previous two years. One critical observation which must be included with these "anomolous" observations is that 1983 and 1984 were extremely dry years. Actual seed weights of control plants during 1983 and 1984 were only 20-30% of those harvested in 1981 and 1982. Therefore, it is clear that these 1983 and 1984 data are not representative of true (normal) field trends. This graphically illustrates the importance of multiyear studies and emphasizes the need to monitor other environmental variables in addition to UV radiation. Other parallel field studies have shown that the effects of UV-B radiation can be masked by other stresses such as drought or mineral deficiency.

Despite the broad range of experimental protocols and dosimetry used by various investigators, it appears that increases in solar UV radiation could potentially have a deleterious impact upon global crop yields. Even discounting the data from the three unfiltered lamp studies (Ambler, Rowland, and Maher 1978, Esser 1980, Hart et al. 1975), there are still more instances of significant reductions in yield than reports of no effect. Of key importance is the fact that only three field studies (Biggs et al. 1984, Eisenstark et al. 1984, Teramura 1981-1985) include multiyear observations in which longer-scale environmental variability has been taken into consideration. Furthermore, only mid-latitude regions have been analyzed to date. It is reasonably likely that increases in solar UV will decrease crop yields in tropical regions as well.

RISKS TO YIELD QUALITY

Biggs and Kossuth (1978) reported that the number of abnormally shaped tomato fruit decreased 11 to 41% under increased levels of UV-B radiation in the field. They also reported a 6 to 23% reduction in the number of culls (rots, cracks, sunscald, etc.) in plants receiving a moderate UV-B dose, while those receiving a low dose produced a 10 to 34% increase in culls. Mean potato weight of grade A large potatoes increased 3 to 13% under increased levels of UV-B radiation, but not in any other grade categories. In neither case was a linear relationship between UV dose and plant response demonstrated.

In a field study conducted in Beltsville, Maryland, Ambler, Rowland, and Maher (1978) reported that the sugar content in sugar beets significantly increased by 17-21% with increasing UV-B irradiance. However, they only observed these significant increases in plants directly under the lamp irradiation system and not in plants receiving a comparable UV-B dose at some distance away.

Teramura (1982-1985) examined the effects of UV-B radiation on seed protein and lipid concentrations of soybean grown in the field at Beltsville, Maryland (Exhibit 11-6). Overall, the effects of UV radiation were relatively small but some were nonetheless significant. Seed protein concentrations declined under elevated levels of UV-B radiation in two of the four years (up to 5% reduction) in cultivar Essex. Seed oil concentrations were reduced by 3 to 5% in cultivar Forrest in 1982, the only year in which it was measured in Forrest. Williams showed a slight reduction in seed oil content, with a maximum reduction of 10% reported in 1984. Therefore, although seed yield may not be affected in some soybean cultivars, UV-B radiation may reduce its quality.

The extent of UV-mediated alterations in yield quality cannot presently be estimated with any degree of confidence due to the paucity of experimental data at hand. Nonetheless the consistent reductions in yield quality in soybean suggest that the risk may be quite high in some crops.

INCREASES IN DISEASE OR PEST ATTACK

Esser (1980) reported a significant decrease in the number of aphids found per plant but no significant difference in the spidermite population with increase UV-B radiation. Although the results suggest that UV-B radiation can have potentially beneficial effects on pest control, these conclusions must be judged with caution since the observation period was relatively short (less than two weeks).

Growth chamber and _in vitro_ studies of fungal pathogens showed that colorless spores are more sensitive to UV-B radiation than pigmented ones (Carns, Grahm, and Ravitz 1978). Owens and Krizek (1980), however, found that survival of a pigmented spore (_Cladosporium cucumerinum_) was decreased with UV-B radiation due to a delay in germ tube emergence. Other studies (Esser 1980, Biggs et al. 1984) also indicate that there is no clear relationship between spore coloration and UV-B radiation effectiveness.

Three leaf fungal pathogens showed a significant decrease in disease severity with UV-B radiation in a growth chamber study (Esser 1980), and a field study by Biggs et al. (1984) showed no significant difference in disease severity in leaves and seeds under increase UV-B radiation. However, Biggs et al. (1984) and Biggs (1985) found that in a leaf rust-sensitive cultivar of wheat, disease severity increased with UV-B radiation, while in a rust-resistant cultivar, there were no differences in severity.

Semeniuk and Goth (1980) found significant UV-B mediated reductions in potato virus infection on _Chenopodium quinoa_. In this study, virus extract was exposed to UV-B radiation immediately upon its application over the leaf surface. Intuitively, viruses should be highly susceptible to UV-B radiation, since they consist of

EXHIBIT 11-6

Summary of changes in Yield Quality in Soybean Between the 1982 and 1985 Growing Seasons
(Teramura 1982-1985)

Crop	Yield Character	1982 % Change	Significance	1983 % Change	Significance	1984 % Change	Significance	1985 % Change	Significance
Glycine max									
cv Bay	% protein	0 to -5	ns						
	% lipid	-1.4 to +3	ns						
Essex	% protein	-3 to -5	P=0.05	+1 to -5	P=0.05	+1 to 0	ns	-0.7 to 0	ns
	% lipid	-2 to +.5	ns	+2 to -2	ns	-2 to 0	ns	0	ns
James	% protein	+.2 to +3	ns						
	% lipid	-1 to -2	ns						
Williams	% protein	0 to -.2	ns	+.4 to -.2	ns	+3 to +5	P=0.05	0.5 to -1	P=0.05
	% lipid	+5 to +8	P=0.05	-1 to +6	ns	-5 to -10	P=0.05	0	ns
Forrest	% protein	+.5 to +2	ns						
	% lipid	-3 to -5	P=0.05						
York	% protein	-2 to -3	ns						
	% lipid	0 to +3	ns						

nucleic acids encased in proteins, both of which have high UV absorption properties. However, virus sensitivity must be viewed in light of screening offered by the host tissues.

One of the plant defense mechanisms that inhibits fungal development is the production of a class of chemicals known as phytoalexins (Bell 1981). Phytoalexin production in plants can be induced artificially through mechanical injury, high temperature, application of fungicides and antibiotics, and by UV radiation (Bridge and Klarman 1973, Reilly 1975, Bakker et al. 1983). However, excess production can be toxic due to free radical formation (Biggs et al. 1984).

At present, it is difficult to forecast the consequences of increased UV-B radiation in terms of pest and disease damage. From the limited information available, it appears that in some cases UV-B radiation might decrease disease severity while in others it might aggrevate it. The effects vary with pathogen, plant species, and cultivar and therefore appear to be specific rather than general in nature. Further studies are obviously needed to develop a better understanding of the consequences of increased levels of UV-B radiation on specific pests and plant diseases.

COMPETITIVE CHANGES AMONG PLANTS

Many plants have been shown to exhibit a wide range of sensitivity to increased levels of UV-B radiation (Teramura 1983), which could lead to changes in competitive ability within plant communities through differential UV-B resistance (Caldwell 1977). Solar UV exclusion studies (cited in Gold and Caldwell 1983) using natural competing species show large differences in response to present levels of UV radiation. This suggests that current levels of UV radiation may be partly responsible for competition among various native plant species.

Gold and Caldwell (1983) studied crop-to-weed competition in wheat (*Triticum aestivum* L.), wild oats (*Avena fatua* L.), and goat grass (*Aegilops cylindrica* Host) at various planting densities in Logan, Utah, under ambient and UV-B levels simulating a 16% ozone reduction. UV-B appeared to alter growth by the inhibition of internode elongation in wild oat but not in wheat, thus favoring wheat in competition for available light.

Fox and Caldwell (1978) and Gold and Caldwell (1983) examined the effects of UV-B radiation on the competitive interaction of field-grown competing pairs from three plant associations: agricultural crops and associated weeds, montane forage crops, and disturbed weedy associates. Based upon total above ground biomass, there were significant shifts in the competitive balance of some agricultural crop and weed associations. For example, pigweed (*Amaranthus*) was more competitive under ambient UV conditions and alfalfa (*Medicago*) exhibited the competitive advantage under increased UV-B radiation. Under a 40% ozone reduction, wheat (Triticum) had a competitive advantage over wild oats (Avena) and goat grass (Aegilops) but no significant differences were observed with a 16% reduction. In the previous year, the competitive balance was found to be in favor or Avena. It was suggested that this difference was due to a late planting resulting in large water and temperature stresses during seedling development (Gold and Caldwell 1983). Similarly, the weedy Geum had the competitive advantage over Poa grass under ambient conditions, but the balance was shifted under increased levels of UV-B radiation.

These results demonstrate that increased levels of UV-B radiation can alter the competitive interactions to some species. Total harvestable yield, as well as its quality, is altered by the presence of weeds (Bell and Nalewaja 1968, McWhorter and Patterson 1980). Since there are a large number of weeds typically associated with various crop plants, the impact of increasing levels of UV-B radiation upon agricultural systems could potentially have serious consequences if weeds gain a competitive advantage over crops. Even very subtle differences in sensitivity could result in large changes in species composition over time and possibly affect ecosystem function. At this time, however, it is impossible to determine the extent of the risk.

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CMA
CHEMICAL MANUFACTURERS ASSOCIATION

COMMENTS ON HEARING OF
MAY 12, 1987
REGARDING STRATOSPHERIC OZONE DEPLETION

BEFORE THE

SUBCOMMITTEE ON HAZARDOUS WASTES AND TOXIC SUBSTANCES
AND THE
SUBCOMMITTEE ON ENVIRONMENTAL PROTECTION
OF THE
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
UNITED STATES SENATE

BY THE

FLUOROCARBON PROGRAM PANEL
OF THE
CHEMICAL MANUFACTURERS ASSOCIATION

May 27, 1987

2501 M Street, NW • Washington, DC 20037 • Telephone 202/887-1100 • Telex 89617 (CMA WSH)

The Fluorocarbon Program Panel (Panel) operates as a Special Program in the Biomedical and Environmental Special Programs Division of the Chemical Manufacturers Association. It is an international group representing 19 chlorofluorocarbon (CFC)-producing companies from 10 countries. Its research program was initiated in 1972, to investigate the potential effects of CFCs on the environment. The Panel has spent in excess of $19 million to date on research, and has had an annual budget of about $1.7 million in recent years. At least an equivalent amount has been spent by individual companies in support of the Panel's program.

The Panel's research program is aimed at improving the understanding of atmospheric processes and fostering long-term monitoring activities. The Panel is unique among groups supporting research on the ozone and climate issues in having the freedom and flexibility to fund relevant projects anywhere in the world. The Panel solicits proposals and funds research in government, university and private laboratories. In addition to research projects, the Panel sponsors workshops and provides critical travel funds. The latter have frequently been difficult for U.S. government agencies to provide. The Panel plays a key role in promoting international cooperation in many research programs.

Several members of the Panel were present at the joint hearing sponsored by the Subcommittee on Hazardous Wastes and Toxic Substances and the Subcommittee on Environmental Protection on May 12, 1987, regarding stratospheric ozone depletion. Most of this hearing was dedicated to: (1) Antarctic ozone (2) Ozone measurements and (3) Skin cancer. The Panel is concerned with the presentation and interpretation of the data surrounding these issues as indicated at the May 12 hearings. The Panel is pleased to submit for the record the following information, evaluation, and perspective on the three above-mentioned issues.

* * * * *

ANTARCTIC OZONE

CMA's Fluorocarbon Program Panel shares the concerns of Congress and the scientists who presented results of the 1986 National Ozone Expedition (NOZE) about the periodic seasonal loss and recovery of ozone over Antarctica in recent years. Although the NOZE results are important for understanding the Antarctic ozone phenomenon, more information is needed before causes can be established. The Panel cooperated with the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the National Science Foundation (NSF) to develop and fund the NOZE program. NOZE attempted to understand the atmospheric changes that could be responsible for these local, seasonal ozone changes.

The unique character of the atmosphere over the Antarctic continent probably contributes to the conditions necessary for ozone losses to occur. Two types of explanations, both based on the unusual properties of region, are being evaluated by the scientific community.

Proponents of the "dynamical" explanation believe that periodic changes in winds that move ozone into and out of the Antarctic region could cause the observed ozone decreases and the subsequent recovery during the local spring season. Other scientists invoke speculative chemistry, believing that the special character of the Antarctic atmosphere allows certain chemical reactions to occur causing seasonal ozone losses. The actual reason could be either explanation, a combination of the two, or something that has not yet been proposed. Whatever the cause, it is believed that, because of the many unique characteristics of the Antarctic spring, the phenomenon will be confined to that region and season.

Our present understanding of the atmosphere is inadequate to explain the phenomenon. Therefore, it is premature to judge if the anomalous levels of chlorine and nitrogen compounds detected by the NOZE scientists in the Antarctic atmosphere are simply other symptoms of the phenomenon or a part of the cause. Moreover, ozone amounts over Antarctica during the spring of 1986 were greater than those during the spring of 1985. Whether this is the start of a reversal or a one-year fluctuation is unknown.

Many more aspects of the phenomenon must still be explained. To find an explanation, satellite, aircraft-borne, balloon-borne and ground based observations are planned for the spring (August through October) of 1987. This campaign will include measurements of ozone and other atmospheric constituents, and should provide many answers.

The Panel is co-funding these efforts along with NASA, NOAA, NSF and agencies of the New Zealand and British governments. The Panel is presently funding chemistry, analyses of atmospheric measurements, and computer modelling studies aimed at understanding the causes of the Antarctic ozone phenomenon.

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OZONE MEASUREMENTS

The possible effects of trace gases on the atmosphere has led scientists to explore whether a detectable change in global ozone levels has already occurred. Here are some facts:

Ground-based Observations

- Statistical analyses of ozone measurements from a ground-based network of 36 stations over the past several decades show no persistent change in the total global amount.

- The measurements cover a time period which encompasses two solar cycles. The cycles are believed to be significantly related to short-term ozone changes.

- The total amount of ozone overhead determines the level of ultraviolet (UV) radiation reaching the earth's surface. Since total ozone levels are unchanged, recent increases in UV-related effects, such as skin cancer cases, cannot be ascribed to ozone decreases, and are almost certainly related to changes in lifestyle.

Satellite Observations

- Recent observations by one satellite of a declining trend in total global ozone are preliminary and need review. Scientists debate the validity of the observations, because of the need to make large corrections due to changes in the measuring instrument and to remove measurement complications, such as signals caused by volcanic dust.

- A recently published paper comparing measurements made by this satellite instrument and measurements by the network of ground-based instruments concludes that much of the trend observed in the satellite data may be due to uncorrected changes in the satellite instrument itself.

- The measurements are being carefully reanalyzed by a NASA sponsored team of government, university, and industry scientists. The team hopes to quantify any trends. Any short-term trend must be put into context of long-term natural ozone fluctuations which have time scales ranging from days to 11 or more years. The data will be compared with those from other satellites and from the ground-based stations.

- Even if the analysis indicates real changes in ozone amounts, further careful interpretation is needed to identify the cause or causes. Possibilities include: variations in sun activity; changes in the concentration of natural or man-made trace gases; as yet unknown chemical cycles; and changes in air motions.

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CAN SKIN CANCER INCREASES BE ATTRIBUTED TO OZONE CHANGES?

CMA's Fluorocarbon Program Panel believes there is reason for concern about reports indicating an increase in skin cancer. But, the Panel is also concerned about other reports directing attention away from the most likely cause for the increase -- changes in life style in recent generations. Instead, these reports have focused on the misconception that decreasing ozone in the atmosphere is responsible. Further, the release of chlorofluorocarbons (CFCs) to the atmosphere is incorrectly being blamed for the alleged decrease in atmospheric ozone. In reality, there has been no decrease in the amount of atmospheric ozone.

The method by which ozone influences skin cancer is by the amount of ultraviolet-B (UVB) radiation reaching the earth's surface. Ozone, a trace gas present throughout the earth's atmosphere, acts as a filter limiting UVB radiation from the sun. The amount of UVB radiation reaching the earth's surface is determined by the total amount of ozone overhead, usually called "column ozone." The most reliable column ozone measurements come from a network of 36 ground-based monitoring stations located around the world. Ozone measurements at these stations over the past several decades show no persistent change world-wide. Recent increases in skin cancer cases therefore cannot be ascribed to ozone changes.

Calculated projections, using sophisticated computer simulations of the atmosphere that incorporate the best current scientific information, indicate little change in column ozone during the next few decades. These projections assume that CFC emissions into the atmosphere will remain near today's levels. There is no imminent hazard therefore from continued emissions of CFCs at these rates.

Atmospheric models are useful predictive tools for the short term, but are far less reliable beyond the next few decades because uncertainties in input data become too great. Nevertheless, some studies predict very large numbers of ozone-related skin cancer cases 100-150 years from now. These projections, using calculated ozone decreases, assume sustained, compounded growth rates of CFC emissions for over 100 years. Such assumption is highly unlikely. Both government and industry in all major CFC producing countries have accepted the need to limit future growth of CFC emissions on a global basis. A protocol to limit CFC emissions world-wide is being developed under the United Nations Environment Programme's Vienna Convention for the Protection of the Ozone Layer.

STRATOSPHERIC OZONE DEPLETION AND CHLOROFLUOROCARBONS

WEDNESDAY, MAY 13, 1987

U.S. SENATE, COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS, SUBCOMMITTEES ON ENVIRONMENTAL PROTECTION AND HAZARDOUS WASTES AND TOXIC SUBSTANCES,
Washington, DC.

The Subcommittees on Environmental Protection and Hazardous Wastes and Toxic Substances met, pursuant to notice, at 9:33 a.m., in room SD-406 Dirksen Senate Office Building, Hon. Max Baucus (chairman of the Subcommittee on Hazardous Wastes and Toxic Substances) presiding.

Present: Senators Baucus, Chafee, Breaux, Stafford, Graham, Durenberger, and Symms.

OPENING STATEMENT OF HON. MAX BAUCUS, U.S. SENATOR FROM THE STATE OF MONTANA

Senator BAUCUS. The subcommittee will come to order.

Yesterday we addressed the basic question of CFC production and its relation to stratospheric ozone depletion. We more particularly focused on the science of ozone depletion from a global point of view. Second, we focused on the Antarctic hole, exploring various causes of the hole; chemical, dynamic, and solar. Third, we addressed some of the health effects of ozone depletion, particularly its effect on skin cancer and the immune system, retina damage, and on crops and aquatic effects as well.

Today we are going to focus more on substitutes; that is, the degree to which substitutes are available or can be developed, the costs, the time frame, and also exploring the U.S. relationship to the development of substitutes in other countries—that is, the degree to which the United States should be a leader in the development of CFC substitutes or on the other hand the degree to which the United States should only act multilaterally—that is, only in conjunction with any U.N.-imposed agreement.

It is my preference that because the problem is so acute—that is, ozone depletion is so acute—that the United States should be a leader. We should not sit back and pass the baton of leadership to another country or another group of countries, but we the United States should forge ahead as the true test of leadership.

We begin the hearing with our first panel. This panel will include Ms. Eileen Claussen of the EPA; Dick Lagow; and Mr. Phillip Fairchild, of Oak Ridge.

Would you three please come forward?

Before we begin, I will ask if the other Senators might have statements. Senator Chafee, do you have a statement?

OPENING STATEMENT OF HON. JOHN H. CHAFEE, U.S. SENATOR FROM THE STATE OF RHODE ISLAND

Senator CHAFEE. Yes. Thank you, Mr. Chairman. First I want to say again how much I appreciate and we all appreciate your organizing these hearings with Senator Mitchell, who of course is tied up with the Iran select committee.

I have a statement I would like to put in the record, Mr. Chairman, but there are just a couple of points I would like to make.

I know that the industry representatives will argue that since this is a global problem, unilateral action will not solve it and will only penalize U.S. industry. There is something to that, and global action is ultimately needed. We all agree with that, but if the international talks fail to produce an acceptable agreement, the U.S. and a number of like-minded countries can make a difference. If we go forward and do the right thing to protect the environment and use our clout—ours meaning theirs and the others that will go with us and ourselves as world trading partners.

We are big players in this game, there is no question about it. I believe our actions can force other nations to follow suit while at the same time we can protect our domestic industries. I don't think any of us want to do anything on this committee that is going to put us, our industries, at a drastic disadvantage, or any disadvantage, if we can help it.

There are going to be analogies drawn to the 1978 aerosol ban and the fact that the Europeans didn't follow our example. But the trade implications of our proposals in connection with the next step are far larger in magnitude than those raised by the aerosol ban. I think we can be much tougher in the steps we take.

Some people will argue that even the threat of unilateral action will undercut the ability to reach an international agreement. You touched on this in your remarks, Mr. Chairman. This is a possibility we all worry about. However, last November I had the privilege of going to Europe and discussing this with some of the European governmental environmental leaders. I firmly gathered the view that the United States by going ahead unilaterally can have a tremendously positive effect on international negotiations and on the actions of the other countries.

We have a problem, and we have to find a solution. And whether we end up acting on a multinational basis, which we would like to do if we can, or bilateral agreements or unilaterally, somehow we have got to push this system forward.

Experience from the early 1980's has taught us that, without Government pressure, there will be no market for CFC substitutes. I think what we have to learn from the producers as well as the industries is whether a 6-to-8-year phaseout is realistic, and if it's not realistic, then how much time do we need? That is what we want to hear.

We heard some pretty tough evidence yesterday. The average amount of chlorine found in the atmosphere today is three to four parts per billion. With that low level, we are experiencing a collapse of ozone over the southern hemisphere each October, and we have seen global depletion in the upper stratosphere.

No one predicted the Antarctic hole. The scientific witnesses we heard yesterday all agreed on that. At the current emission rates we are risking a global ozone collapse. With a production freeze—the three to four parts per billion will rise to about nine parts per billion and cause up to 16 percent depletion at the higher altitudes.

One final point. When we talk about substitutes, I don't think our minds should always be on, "Well, this CFC 11 and 12, if that's not right, let's go to 23 or whatever it might be." There are product substitutes as well as chemical substitutes. For example, polystyrene egg cartons made with CFC's and there might be a pentane as a substitute. But is the only place we can look? Maybe we ought to say, "Well, we can switch to fiberboard egg cartons. The world existed before there were polystyrene egg cartons, and that is just the simple point. Some of these things, we may just plain have to get along without.

There is going to be testimony that we can't wrench around the system too quickly. I checked on what happened to aerosol production in the United States. It dropped from a half a billion pounds, 500 million pounds, in 1974 to less than 25 million pounds, one-twentieth as much, 6 years later. And somehow, our Nation survived.

So I am not convinced that American or any other producers have a constitutional right to continue products that cause permanent harm to our world or to our citizens. I just do not think that is a guaranteed right under our law.

So, we look forward to hearing from these witnesses today, and I want to thank you, Mr. Chairman.

[Senator Chafee's written statement follows:]

OPENING STATEMENT OF HON. JOHN H. CHAFEE, U.S. SENATOR FROM THE STATE OF RHODE ISLAND

We heard a number of interesting facts yesterday that should be summarized at the outset of today's hearing.

First, current scientific models of ozone depletion and the use of global "averages" are probably underpredicting and masking the true environmental consequences of ozone depletion.

Second, the global freeze on production of CFCs that is being urged by industry and considered at the on-going international talks would result in depletion of the ozone layer. In fact, even the most stringent option being considered—a 50 percent reduction in harmful CFCs—is predicted to result in significant global depletion.

Third, the "hole" over Antarctica is actually an annual collapse over significant portions of the southern hemisphere, including the tip of South America.

Fourth, no one predicted the "hole" and we are risking similar collapses elsewhere.

Fifth, although more work needs to be done, chlorine from CFCs appears to be "the smoking gun" in Antarctica and, in the upper stratosphere, over the rest of the globe.

And sixth, in addition to the predicted and much publicized increases in skin cancer that will result from ozone depletion, we are likely to see more eye damage, suppression of the immune system, disruption of the aquatic food chain, reduced productivity in crops and damage to other plants and forests.

That outlines one-half of the problem. The other half of the problem has to do with finding a way to develop, market, and begin using safe substitutes for CFCs as quickly as possible.

I know that industry representatives will argue that, since this is a global problem, unilateral action will not solve the problem and will only penalize U.S. industry. I agree with that up to a point.

Global action will ultimately be needed, there is no question about that. However, if the international talks fail to produce an acceptable agreement, the U.S. and a number of like-minded countries can make a global difference if we go forward, do the right thing to protect the environment and use our clout as world trading partners. This will force other nations to follow suit while, at the same time, protect our domestic industries.

Analogies to the 1978 aerosol ban and the fact that the Europeans did not follow that example are not convincing. The trade implications of our proposals are an order of magnitude larger than those raised by the aerosol ban.

Some people argue that even the threat of unilateral action will undercut the ability to reach an international agreement. This is a possibility that I worried about. However, discussions I held in Europe last November and information I have gathered since then, convinced me that our proposals are having a positive effect on the international negotiations.

We have a problem and now we have to find a solution. Whether we end up acting on a multinational basis, through a series of bilateral agreements, or unilaterally, we have to push the system forward.

Experience from the early 1980's taught us that, without government pressure, there will be no market for CFC substitutes.

We need to learn from the producers, we well as from the industries using CFCs, how fast we can drive the system to eliminate these chemicals. If the 6 to 8 year phase-out that is in our bills is unrealistic, tell us how much time you need and show us how you will use that time. We are open to suggestions but the burden is on you to justify a longer time frame.

Why do we have to eliminate these chemicals? Why isn't a freeze at current levels good enough? The following numbers speak for themselves.

The average amount of chlorine found in the atmosphere today is 3 to 4 parts per billion. With that low level, we are experiencing a collapse of ozone over the southern hemisphere each October and we have seen global depletion in the upper stratosphere. No one predicted the Antarctic hole and, at current emission rates, we are risking a global ozone collapse. With a freeeze, the 3 to 4 parts per billion will rise to about 9 parts per billion and cause up to 16 percent depletion at high latitudes in 50 years.

Without proof that such a basic, man-made change in our atmosphere is safe, a freeze by itself is unacceptable and irresponsible.

One final point, when talking about substitutes, it is important for everyone to be thinking about product substitutes as well as chemical substitutes. For example, polystyrene egg cartons can be made with CFCs or with pentane, a chemical substitute. On the other hand, we can all switch to fiberboard egg cartons. This is a simple, isolated example but it serves to make the point.

Undoubtedly there will be testimony that we cannot wrench around on production of CFCs too swiftly. It is well to recall that the ban on aerosols in the U.S. caused production of CFCs for aerosols to drop from 500 million pounds in 1974 to less than 25 million pounds, one-twentieth as much, 6 years later. And our country survived.

I am not convinced that American or any other producers, have a constitutional right to continue to produce products that cause permanent harm to our world, to our citizens.

I look forward to hearing the witnesses today and working with them to solve this problem. Several useful comments about our bills (S. 570 and S. 571) have already been received, particularly with respect to the role of CFC 22 as part of the solution.

It is unrealistic to phase-out the use of CFC 22 and that was never our intention. But I am still worried about unlimited growth in any chemical that has the potential to deplete the ozone layer. More work will obviously need to be done there.

Senator **Baucus**. Thank you, Senator.

Senator Breaux?

OPENING STATEMENT OF HON. JOHN B. BREAUX, U.S. SENATOR FROM THE STATE OF LOUISIANA

Senator **Breaux**. Thank you very much, Mr. Chairman. Thank you for chairing these very important hearings. This issue has been around for many, many years. After over a decade of congressional hearings we have still not decided what to do or how to solve the problem. I am looking forward to hearing the witnesses. At 10 I have to preside on the Senate floor, so I have to leave, but I will be back as soon as I finish that task.

No matter what the solution is, I think ultimately it is going to have to be a global solution. It does us no good whatsoever to reduce our production of a harmful product by 90 percent to have other countries pick up that 90 percent and continue to produce it. We cannot look at this as a U.S. problem. It is indeed a global problem and we have to have global solutions. So I am looking for ways in which we can encourage other countries to participate with the United States in seeking a solution.

I do not like the concept of us banning our production while others just come in and increase their amount to make up for that reduction that we have in the United States. The Earth's atmosphere doesn't care whether it's coming from the United States or from Canada or from Europe or from Japan, the same amount of damage is done. And until we come up with a global solution to the problem, it is not going to work just by us doing it alone. We can be the leaders, but we have to take some followers with us; otherwise, we are not going to have a solution to the problem that we all seek.

Thank you, Mr. Chairman.

Senator BAUCUS. Thank you, Senator.

Ms. Claussen, we will hear from you.

STATEMENT OF EILEEN CLAUSSEN, DIRECTOR, OFFICE OF PROGRAM DEVELOPMENT, ENVIRONMENTAL PROTECTION AGENCY, WASHINGTON, DC

Ms. CLAUSSEN. Thank you very much, and good morning. I am pleased to be here today to discuss our preliminary analysis on substitutes for ozone-depleting chemicals and on the costs and benefits of measures to protect stratospheric ozone. I would like to summarize my statement, which we have submitted for the record.

Senator BAUCUS. It will be included.

Ms. CLAUSSEN. The data that I am going to be presenting are drawn from the analytical efforts we have been pursuing to support both our domestic rulemaking and our international activities on CFC's. They are preliminary results and should be viewed with some caution. In our analytical process we have collected data on seven use categories for CFC's—solvents, refrigerants, foam blowing, et cetera—and have looked at specific applications for each, in other words, mobile air conditioners, refrigerators, et cetera. Then for each application, we have analyzed choices that can be made to reduce the use of CFC's in the short, medium, and long term.

Let me give some examples. In the short term, up to three years, there are three options available for the reduction of CFC 11 use in centrifugal chillers: use of alternate leak testing gas, recovery at service, and recovery at disposal. Each of these could result in substantial reductions in the use of CFC's at a cost of less than 15 cents a kilogram.

Another example would be replacing the seals on dry cleaning units that use CFC 113. This could result in a use reduction, we believe, of about 18 percent in the short term.

Moving to the medium term, four to seven years, another set of options typically become available. For polyurethane foam, for example, the use of cotton batting, changes in foam density specifications, and the use of water-blown systems are all possible in the short term. But in the medium term, other choices become available, including the use of carbon adsorption or formic acid systems.

In the longer term, chemical substitutes for CFC's are likely to be used. Fluorocarbon 134A could be used as a replacement for CFC 12 in many applications, or CFC 123 could be used to replace CFC 11 in certain foam applications.

We have taken our analysis of specific uses and options and attempted to estimate the costs and benefits of particular regulatory strategies. For example, our initial work suggests that a freeze at 1986 levels on CFC's 11 and 12 would result in a cumulative cost around $200 million between 1990 and the year 2000 if firms implement the least-cost reduction alternatives that are available.

The cost estimates we have developed can be compared to the benefits that can be derived from protection of the ozone layer. If CFC use continues to grow at 2.5 percent per year, as we have estimated, the number of skin cancer cases in the United States would increase by 105 million and the number of early deaths by two million for those alive today and born through 2075. For a 1990 global freeze on current CFC production levels, 92 million excess skin cancer cases and 1.8 million deaths could be averted. For a 50 percent phasedown by 1996, 97 million excess skin cancer cases and 1.9 million deaths could be averted.

I believe that summarizes the major points in my written testimony, and I would be happy to answer any questions.

Senator BAUCUS. You have set a good precedent here: less than 5 minutes.

Dr. Lagow, why don't you proceed?

STATEMENT OF RICHARD J. LAGOW, DEPARTMENT OF CHEMISTRY, UNIVERSITY OF TEXAS AT AUSTIN

Mr. LAGOW. I, under the auspices of the EPA, have over the last 6 or 8 months organized an international panel of the best fluorocarbon chemistry talent, engineering talent, and even marketing talent that we could find both from the academic sector and across several countries and from the industrial sector. We had on my panel representation from many of the major chemical companies, scientific representation—not so much political representation—who manufacture fluorocarbons all over the world. My panel has amassed a large amount of information on alternative fluorocarbons.

There are two points that I would like to share as testimony today, and then there are several other minor things that I would like to get across, and then I would be happy to answer questions.

The first message is, I think, that it should be recognized that the chlorofluorocarbons that are on the market right now are extraordinarily inexpensive, around 60 cents to 75 cents a pound. The reason for this is that this chlorofluorocarbon technology is based on a process known as the Swarts process, invented by a Belgian chemist years ago, so long ago in fact that Belgium doesn't even have outstanding fluorine chemistry anymore. This is actually very important in considering what sorts of things we are going to do about alternative chemicals, particularly with respect to regulation to create a market for alternative fluorocarbons and other alternative compounds. And I will explain why.

These chlorofluorocarbon products that we have today for many important and diverse uses come from very inexpensive starting materials. They come from chlorocarbons which comes from companies like Dow and others situated on salt (NaCl) domes and produce chlorine at around 11 cents a pound. The other raw material is hydrogen fluoride, which is a very inexpensive commodity chemical.

Now, there are fluorocarbons, (not necessarily chlorofluorocarbons) (30–50¢ lb), thousands per year, made all over the world that could, any one of them, be potentially useful as alternative materials for, say, refrigerants, foam blowing—price is a problem there; for electronic cleaning fluids and grease-cutting fluids like 113. These materials have not been looked at in that light because most other fluorocarbon processes cost at least six dollars a pound and on a large scale twenty dollars a pound could be required to manufacture them.

Now, the reason that this is important to you gentlemen and the people who are making regulations is—and this is our central message from the committee—there will be no market for alternative fluorocarbons unless there are strong regulations over a reasonable time scale.

As you gentlemen know, we simply couldn't have any incentive other than, say, goodwill, and we can't always depend on that sort of thing to drive an industry, and we are talking about many industries. There would be no incentive for users to go from higher-priced chemicals from the 60-cent-a-pound material. In fact, these chlorofluorocarbons have such good cost property ratios, they are so cost effective that they are used in many, many applications for which you could use other chemicals—uses for which you don't need the super properties of a chlorofluorocarbon.

Fluorocarbons (as opposed to chlorofluorocarbons)—have even better properties, but these materials don't have the solvent properties and some of the other properties that chlorofluorocarbons do.

Aside from the important conclusions of my panel that the regulations, more than any anything else, create a market for these other materials, the committee—concluded that even if Swarts chlorofluorocarbons failed, other fluorocarbon alternates is another big point to make just a little later, and that it could be developed at $5–$8 a pound. Implementation of alternative chemicals is going to require funding for a research backup effort in case any of these chemicals that we have tabbed as the leaders on this committee fail.

As I have said, on a large scale most of the processes that put fluorocarbons on the table at, say, DuPont or 3M would definitely command a four-to-six-dollar-a-pound price and could not compete with Swarts chlorofluorocarbons.

Now, we have picked—the committee picked—as leading candidates to make inroads on the problem, the ozone problem, 134A and 123, as Ms. Claussen has indicated. The main reason we picked these compounds is that more is known about them because they have, like you said, I believe, Senator Chafee, CFC numbers, and are made by processes similar to Swarts technology. But the problem that we have had that is higher priced fluorocarbons have not in general been screened or considered for such applications.

These materials, 134A and 123, are also manufactured by processes that are pretty cheap. DuPont, as you may have read, made an announcement with price parameters very recently, actually as part of our panel meetings, that projects that such compounds could be made possibly in some cases as low as $1.25 in the best case in large production, to $2 or $3 a pound, and their highest projections were four or five ultimately. If that's true, again this inexpensive process would prevail and other technology couldn't compete. You would end up with Swarts chlorofluorocarbons, hopefully ones that would, as all of the studies indicted, break down in the troposphere, and cause us to have a better situation environmentally.

Senator BAUCUS. Doctor, we are going to ask you to summarize your testimony, please.

Mr. LAGOW. Sure. Well, I have only one more point to make. That is that the compounds that we have picked could fail for toxicity reasons, they could fail for production reasons, and our panel feels that this is important enough where about $3 million a year worth of research should be funded as backup research in case one of these things fails to make new materials, to screen the vast number of known materials.

There are uncertainties on the tropospheric chemistry of 134A and 123, not probabilities of things happening, but uncertainties. And there are some uncertainties about byproducts of these things in the atmosphere.

My summary statement would be that if we are going to make things go on alternative fluorocarbons, that strong regulations over a reasonable time scale are absolutely necessary to stimulate industry and create a market for industry to operate in.

Thank you.

Senator BAUCUS. Thank you very much, Dr. Lagow.

Mr. Fairchild?

STATEMENT OF PHILLIP D. FAIRCHILD, OAK RIDGE NATIONAL LABORATORIES, OAK RIDGE, TENNESSEE

Mr. FAIRCHILD. Thank you, Mr. Chairman. I am also pleased to be here today to participate in these hearings and to discuss some of the research at Oak Ridge National Laboratory that relates to the CFC ozone protection issue.

ORNL is the Department of Energy multiprogram laboratory that is operated for DOE by Martin Marietta Energy Systems. The work in which I involved is in the energy conservation research program.

Why are ORNL and DOE interested in this issue, and what is our role? Well, first we feel there is a potential for serious national energy impacts associated with CFC restrictions. Energy-related uses account for a major share of CFC 11, 12, and 22 production. Insulation, air conditioning, and refrigeration for buildings and transportation account for at least forty percent of the ozone-depleting potential. Our role is in R&D on alternatives for these CFC uses. The Federal Governments' technical expertise is in the DOE conservation program and in their national laboratories, and we have been working with these same industries for over 10 years on energy-related problems.

What we recommend is a very broad-based perspective on technology options, not just focusing on chemical substitutes. Most of the currently proposed technical solutions for substantial reductions, such as new chemicals, are five to ten years away and involve significant uncertainties—as has already been pointed out—about technical issues plus health and safety, economic, energy, and environmental impact issues. Backup solutions are therefore required.

My written testimony provides some examples of other possible options that are non-CFC technologies; for example, absorption and novel thermodynamic cycles that do not even use CFC chemicals, or advanced insulations that have even better insulation properties than foams and do not use CFC's. These are currently being researched by DOE/ORNL, but are not widely considered in the context of CFC substitutes.

Therefore, we recommend a comprehensive, technically based effort to systematically evaluate these alternatives to provide a range of options. We believe that Government and industry can work together and can cooperate in developing these needed technological solutions.

Again, my written testimony describes in more detail an R&D planning process and a program that covers three major areas: the first being substitute chemicals; the second, containment, recovery, and recycling technologies; and the third, new cycles and materials.

We recommend that these three avenues be pursued in parallel to develop near-term, mid-term, and long-term solutions. We feel that the more extensive the list of CFC's that are affected and the more severe the restrictions have to be as far as reduction targets are concerned, the most important will be the role of new technology and R&D.

Our program would include elements such as cost-shared development projects between industry and Government, cooperative agreements, and extensive technical information exchange.

Another issue that underlies this whole rationale for this program is the threat of foreign competition, which is already strong in several of these CFC-dependent U.S. industries. The technical and market changes that are required by CFC restrictions, together with the limited R&D budgets in a lot of these industries could make these industries vulnerable to being leapfrogged by advanced technology from foreign-supported R&D. I am sure you know where a lot of that competition will probably come from. We have had interaction with, for example, the Ministry of International Trade and Industry in Japan to know that they are also very aware of this issue and the technology opportunity that it may provide in terms of competition.

The program we have recommended involves an estimated DOE budget of about $1 million per year for 4 to 5 years, plus substantial industry cooperative support. I think that is probably in line with the budget figures that were mentioned previously. Of course, $3 million would be better than $1 million. But that is our current estimate.

The DOE program in its formative stages has already been closely coordinated with EPA, and we would continue to closely coordinate with EPA in this activity.

We share the concern about this global environmental threat. We feel it is important to take a positive step and provide the CFC-dependent industries with the technical support incentive for early identification and development of CFC alternative technology. The coordinated Government-industry program on alternatives that I have described would offer industry the technical expertise of the DOE National Laboratories and an opportunity for cost-shared collaborative research projects. I hope that our input and future contributions can help stimulate industry and Government cooperation in this area.

I would be glad to furnish any additional details.

Senator BAUCUS. Thank you very much, Mr. Fairchild.

I note that Senator Stafford and Senator Graham have joined us. Senator Stafford, do you have an opening statement?

Senator STAFFORD. No, I do not have an opening statement. Thank you, Mr. Chairman.

Senator BAUCUS. Senator Graham?

Senator GRAHAM. No statement, Mr. Chairman.

Senator BAUCUS. Dr. Lagow, can you tell me a little more about your panel?

Mr. LAGOW. Yes.

Senator BAUCUS. Who all is on it, and what was your mission?

Mr. LAGOW. I think I should have explained to you that we had the three top academic fluorocarbon chemists in the United States serving on the panel and also the best individual academic fluorocarbon chemist in Japan, Germany and England, respectively. The industrial experience of the panel was extraordinary. For example, a member of the panel, Don LaZerte, has been for many years the director of the entire chemistry research division of 3M, another member, Andy Woyteck, is the Director of Fluorochemical Research at Air Products and Chemicals, Inc., and a distinguished member, Luther Chien, was Research Director of Du Pont's Freon Division for well over ten years. Also we have the Director of Allied's central fluorochemical lab located in Buffalo (Dr. Marty Robinson), Dr. Gene Stump who has been Vice President and Marketing Director of PCR, Inc. of Gainesville, Florida, our country's largest supplier of laboratory-scale fluorocarbon chemicals, and finally Dr. Masaaki Yamabe who is Director of Chemical Research at Asahi Glass Co., Ltd., Japan's largest and most innovative fluorocarbon operation and perhaps Japan's largest chemical company.

I will supply a complete list of the panel members.

[The list referred to follows:]

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Senator BAUCUS. Who sponsored you?

Mr. LAGOW. The idea for the panel and the funding came from John Hoffman of the Environmental Protection Agency who reports to Ms. Claussen.

Senator BAUCUS. And they paid for it?

Mr. LAGOW. Yes.

Senator BAUCUS. Okay.

Mr. LAGOW. That's correct.

Senator BAUCUS. And what was the mission?

Mr. LAGOW. Well, the mission was to study the status of alternative chemicals and screen all of the available materials for effective replacement of chlorofluorocarbons that were suspect.

Senator BAUCUS. Can you tell me how much effort is being devoted to developing substitutes presently; and second, how much more effort would be needed, assuming the producing counties were to agree to a freeze and also a reduction, a phaseout, to say, about 90 percent of current usage over, say, 6 or 7 years?

Mr. LAGOW. Yes. I think I can.

Senator BAUCUS. Those are two separate questions. How much is now being devoted; and second, how much more effort would be necessary if we all knew today in the world that the rules we were operating under beginning, say, January 1988?

Mr. LAGOW. Surely. Well, the first question, almost all of the international chlorofluorocarbon manufacturers have had what I would call a "backup effort on alternative chlorofluorocarbons and have amassed a number of patents and some preliminary information on toxicity, which our committee determined, in this, 4-to-7-year period that you mentioned as being the bottleneck.

The studies of these compounds have accelerated in the last two years. I believe some of the major producers had programs about 3 to 5 years ago that were a bit stronger, but then when there were no regulations, some of the efforts slacked off. Now, because the——

Senator BAUCUS. Excuse me. I have other questions to ask.

Ms. Claussen, could you address the question, please; how much is being spent, how much time and effort, and how much more would have to be spent, assuming that we were to move to a global freeze with, say, a 7-year phaseout to 90 percent?

Ms. CLAUSSEN. I think Dr. Lagow is partly correct, that there has been a recent increase in the amount of money that the industry is spending on substitutes. We think there are more things that could be done and that there could be some expansion of that. It isn't clear, however, that substitutes would be available and marketable, say, in 4 years, which was the bottom end of your range. We think that 5 to 7 years is probably more realistic, given the needs to finish the development, do the toxicity testing, and have the users try out the chemicals and make sure that they can use them in their products and processes.

Senator BAUCUS. Have any of your efforts looked at quantifying the external costs of CFC production and usage? By that I mean as a business proposition; sure, a company wants to do a good job and increase its bottom line. But one of the costs which are not internalized is the external cost of ozone depletion and the effects on skin cancer or on the other health effects on crop and aquatic and biotic effects that occur.

Has anyone tried to quantify those external costs; what the cost to society for a certain percentage increase of skin cancer or breakdown of immune systems and so forth? Has anybody tried to quantify those costs, that you are aware of?

Ms. CLAUSSEN. Actually, we are doing that as part of our regulatory analysis that is looking at various options, costs, and benefits. I don't have dollar figures for you, but I can tell you that the ratio of the benefits—for example, in reduced skin cancers and so on—compared to what we view the cost is incredible. The ratio is heavily weighted on the benefit side.

Senator BAUCUS. Could you expand a little bit more on that point, please, to tell us what you mean by that?

Ms. CLAUSSEN. If you look at the costs of the cancers and attach some value to a life, (which is not an easy thing to do and something which actually a lot of people have a lot of difficulty doing), and then look at the costs of new chemicals and new processes, and compare the dollars on the benefit side to the dollars on the cost side, you usually look for a ratio where the benefits exceed the costs. In this case you are looking at something where the benefits not only exceed but are multiple times greater than the costs.

Senator BAUCUS. Do either of you, Mr. Fairchild or Dr. Lagow, have any views on that point? First, how you quantify grief or the dollar value you'd place on the external costs; and second, what the cost-benefit ratio might be, to the best you could determine it?

Mr. LAGOW. Well, that would be very hard to quantify, but it's obviously very high.

Senator BAUCUS. That the benefits in your view, are obviously much higher than the costs of developing the substitutes?

Mr. LAGOW. Surely. Even with a mercenary cost accounting situation.

Senator BAUCUS. Mr. Fairchild?

Mr. FAIRCHILD. I don't have anything to add. I would defer to EPA on this question, I think.

Senator BAUCUS. Mr. Chafee?

Senator CHAFEE. Thank you, Mr. Chairman.

Ms. Claussen, I think your statement was a good one. Why didn't you get it up until today?

Ms. CLAUSSEN. As you know, we have to go through an interagency clearance process, which took a little longer than is usual.

Senator CHAFEE. OMB give you a difficult time?

Ms. CLAUSSEN. It did take a fair amount of time.

Senator CHAFEE. On page 7, you got fairly specific, which I think is excellent. You really didn't equivocate. Maybe that's what took it so long to get through.

Let me ask you this, Ms. Claussen. When you did your studies, did you look at any product substitutes as opposed to chemical substitutes?

Ms. CLAUSSEN. Yes, we did. In fact, those are the ones that are available in what we would call the short term.

Senator CHAFEE. One of the chemicals that Dr. Lagow was talking about, and which you mentioned, of course, FC 134A, could you discuss that briefly? What is the toxicity situation with that?

Ms. CLAUSSEN. My understanding is that the tests are not fully completed, but that so far it looks pretty good.

Senator CHAFEE. Dr. Lagow, you talk about product substitutes. What can you tell us about expandable polystyrene bead board?

Mr. LAGOW. Well, polystyrene is the area—polystyrene, polyurethane—is the area that is actually most cost-sensitive in all of these applications. I think the producers of polystyrene and polyurethane foams actually have real trepidations even about the low costs that Du Pont projected over a 10-year period with full-scale production for 134A and 123. My panel felt that in those industries, that unless one needed really low thermalconductivity, that many of these people would at the higher cost be forced to use alternative materials, like carbon dioxide and hydrocarbons for foam blowing agents.

Senator CHAFEE. Dr. Fairchild, at the top of page 3 of your testimony, you have something rather interesting. In Japan, about 80 percent of all large commercial buildings are now cooled with absorption chillers. The Japanese are presently clear leaders in the production of this equipment, and so forth.

If the Japanese are using it and we are not, why are we not?

Mr. FAIRCHILD. Well, a combination of two things, really, I think. In Japan there is a national policy about trying to balance the use of different fuels, and they have basically by Government policy caused a lot of this use of absorption, which is a gas-operated or heat-operated type of cycle. The other thing is that basically the Japanese have double-effect chillers, as they are called, which are basically the highest efficiency absorption equipment that is on the market right now. There is a U.S. company that makes a similar kind of equipment, but absorption is just not that strong a market in the United States.

Senator **Chafee**. Well, is there a downside to these absorption chillers? Do they have adverse effects somehow, environmentally, healthwise?

Mr. **Fairchild**. No. I think this represents a viable technical solution. I think it's a matter of economics primarily, you know, just competing economics.

Senator **Chafee**. It's more expensive?

Mr. **Fairchild**. It's more expensive. Right. But it's a combination of efficiency and cost. Right? Operating costs as well as first costs, in other words, must be considered.

Senator **Chafee**. Both you and Dr. Lagow have urged the Federal Government to spend some more money on this. Why does the Federal Government have to do the research for private industry? They are going to benefit out of it; why shouldn't they do the research?

Mr. **Lagow**. Well, private industry will certainly do a good job on 134A and 123, except I think the academic community could contribute a lot there on things like tropospheric chemistry, breakdown of products in the atmosphere, which aren't understood—for example, there is the possibility that 134A could break down into trifluorocetic acid as a byproduct that we don't know a lot about what trifluorocetic acid does. The most significant cost for toxicology and for scale-up will be covered by industry.

On the new chemicals, the things that we would use as a backup—if, for example, some of these chlorofluorocarbons that you brought up failed—if we didn't fund things with the Federal system, we would probably be omitting the help of the academic community all over the U.S. and so forth in this effort.

For example, there was an international fluorine meeting in Florida, which was addressed by some of the Johns Hopkins staff people, and the international fluorine community really wasn't fully aware of this problem. These are the people who are most talented in terms of putting alternative fluorocarbons on the table. There is no funding in the area for these talented people to assist and really not a whole lot of activity because the Swarts area is an old area, as I told you.

Senator **Chafee**. Okay. Fine. Thank you.

Mr. **Fairchild**. Senator, can I respond to that, please, sir?

Senator **Chafee**. Quickly, briefly.

Mr. **Fairchild**. Okay. Basically, in the user industries R&D resources are limited. I think most of what you have heard is from the producer industries, the chemical industries, who have larger R&D budgets. Many of the user industries do not have such R&D budgets, and especially to take not only what they think is the most promising path but also to have some alternative, higher-risk backup path covered. I just think that the Federal—for example, the DOE programs have done this in the energy conservation area on higher-risk research, and I think the same thing applies in this area because it is a national and an international problem.

Senator **Chafee**. Let me just ask one final question. Who sets your priorities? What you are talking about is so modest here. You say $1 million. Dr. Lagow says $3 million. I don't want to be scornful of million-dollar sums. But nonetheless, in the total budget of the United States, it's not much, and I suspect it's not much in your total research monies. Who gives you the priorities? Why shouldn't that have high enough priority to come under the envelope or the cover of your current existing budget?

Mr. FAIRCHILD. Well, perhaps it should be a higher-priority item. It basically is not really covered in any of the existing DOE energy-related budget. It's sort of an area that has resulted from an environmental issue, and maybe R&D on technical alternatives wouldn't normally fall to EPA. But DOE has had many years of experience with these same industries, and, basically the issue has energy consequences so DOE would have an interest in it. And it would be a relatively large budget item—the sum we're talking about, since our overall budget for this kind of research is only about $6 million annually.

Senator CHAFEE. Thank you.

Senator BAUCUS. If I might interrupt, we have to vote now. But I wonder if I could ask each of you a question if you could answer it very, very quickly.

The question is this: You know what the environmental movement is saying about ozone depletion, you know what the industry is saying about substitutes. There is some variations and differences, but basically, they're saying, "Go slow. Substitutes cost a lot of money," et cetera. I would like each of you to tell me, in about fifteen seconds each, the degree to which in your professional judgment American policy should be to phase out CFC's in this country; that is, what degree of phaseout, over what period of time? Just a rough, rough guess, a rough, rough estimate. Ms. Claussen?

Ms. CLAUSSEN. I would really love it if you would ask the administrator tomorrow.

Senator BAUCUS. All right. There is some wisdom in that strategy.

Dr. Lagow?

Mr. LAGOW. Well, there are many, many uncertainties about even what the rate is in the——

Senator BAUCUS. In 15 seconds.

Mr. LAGOW. I think that——

Senator BAUCUS. The bottom line?

Mr. LAGOW [continuing]. We should do it as fast as we can because we can't afford not to, and that would be about 50 percent in seven years or something in that range.

Senator BAUCUS. Mr. Fairchild?

Mr. FAIRCHILD. I was hoping you wouldn't ask us this question because I don't think we necessarily agree with EPA. But I think our estimate is more like a 15-to-20-year period.

Senator BAUCUS. Okay. Thank you very much.

The hearing will recess—I hope for only about 6 or 8 minutes.

[Recess.]

Senator BAUCUS. The subcommittee will come to order.

Our next panel includes Dr. Elwood Blanchard, from Du Pont; and Mr. Robert Traflet, from Allied-Signal, Inc.; Dr. Hugh Farber, from Dow Chemical; Mr. Robert Jeansonne, from Kaiser Chemicals; Mr. Marshall Turner, from Racon; and Dr. Harry Mandell, from Penwalt, Inc.

Gentlemen, why don't you begin. I am afraid I must apologize, though, for potential future inconvenience. There may be a series of votes, but we are just going to have to do the best we can, and I will rush back and forth as quickly as I can so that we can make best use of our time.

Dr. Blanchard, why don't you begin?

STATEMENT OF ELWOOD P. BLANCHARD, GROUP VICE PRESIDENT FOR CHEMICALS AND PIGMENTS, E.I. du PONT de NEMOURS & CO., WILMINGTON, DE

Mr. **Blanchard**. Thank you. Mr. Chairman, members of the subcommittee, my name is Elwood P. Blanchard. I am the group vice president of the chemicals and pigments department of the Du Pont Company. I am appearing before your subcommittee to provide my company's views concerning the questions you have raised.

Based on our analysis of the scientific evidence, we believe that a global strategy should be developed to control emissions of long-lived trace gases, including CFC's. We believe the computer modeling studies show that if emissions of CFC's are controlled, the severe near-term phasedown is not needed.

However, we also believe it is prudent to develop substitutes that are safe to use and which will not have the potential to adversely affect stratospheric ozone. We have concluded that we should continue with research begun in the 1970's which identified promising replacement candidates for CFC 11 and 12. These candidates, like our CFC 22 product, has 5 percent or less of the ozone-depletion potential of CFC 11 and 12 and appear to have both the physical properties and the chemical compatibilities that should permit their use in many applications.

Several major hurdles must be overcome, however, before we can say with assurance that these substitutes will in fact work and can be produced in large volumes. First in our minds is the need to get additional toxicity information, such as lifetime animal inhalation studies, to assure ourselves that the compounds are safe for broad use.

As a part of this program, we have submitted CFC 132B to our Haskell laboratory for toxicity testing. We have just received interim results from our toxicologists conducting a 90-day inhalation study which show adverse effects at all levels tested. I wish to underscore that these results are interim and we will not have definitive findings or recommendations for further study until after it is completed and our experts have had a chance to fully analyze the data.

Nevertheless, this demonstrates the need to move carefully in evaluating the suitability of any substitute for an existing product. We will, of course, provide you with results of this study when it becomes available.

In addition, we are working to develop practical commercial routes to manufacture these new chemicals. Our inability to identify production routes that were as efficient as those employed for CFC 11 and 12 was one of the principal factors that led to our pessimism a few years ago. These problems remain, and it appears that not just minor improvements but inventions may be required to clear the hurdle.

With regard to our customer interface, we need to get sufficient quantities of these products into hands of our customers as soon as practical so that they can provide feedback on the performance of these materials and obtain engineering data for redesign of their products. The response from the marketplace is quite positive. Many of our customers have expressed a strong desire to work with us to evaluate these new compounds.

We do know that none of the compounds identified to date are drop-in substitutes for existing heating, cooling, and air conditioning equipment, and their use would require retrofits that are economically unjustified.

We also know there are no substitutes for major uses of CFC 113, the solvent widely used in the electronics industry. Here, however, emission reduction technology may prove to be a practical way to limit emissions and other restrictions may not be necessary.

In spite of these uncertainties, our research efforts are directed to the development of commercially viable manufacturing processes for these alternatives. However, even assuming success leading to production efficiencies comparable to those for CFC 11 and 12, we know that the chemistry involved will lead to production costs at least double that of current products. The marketplace must be able to bear the higher prices needed to recover these costs.

In closing, we believe there is sufficient knowledge about atmospheric science to conclude that emissions of CFC's should be controlled, and this must be done on an international basis. The cost to the U.S. economy would be magnified if the United States were to undertake unilateral controls. We and our customers are addressing ways to hasten the development of substitutes, and so long as we can see an appropriate return on our efforts, we will continue to vigorously pursue these development efforts.

I would be happy to respond to your questions.

Senator **Baucus**. Thank you, Dr. Blanchard.

Mr. Traflet?

STATEMENT OF ROBERT TRAFLET, PRESIDENT, FLOURINE PRODUCTS DIVISION, ALLIED-SIGNAL, INC., MORRISTOWN, NJ

Mr. **Traflet**. Thank you, Mr. Chairman. Senators, my name is Robert F. Traflet. I am president of the fluorine products division of Allied-Signal, and I appreciate this opportunity to make a brief statement on the chlorofluorocarbon ozone depletion controversy.

Allied-Signal recognizes that unrestrained growth of CFC's and the related uncertainties as to their atmospheric impacts could ultimately lead to unacceptable levels of ozone depletion. We believe prudent action is warranted. Because this problem is global in nature, it requires a global solution. We are pleased to note the apparent progress being made under the auspices of the U.N. environment program to achieve an international consensus, although we have major concerns about the timing and the magnitude of the proposed control measures.

Controlling CFC production internationally at or near existing levels goes a long way toward mitigating any potential atmospheric problems. When you add to this the possible efforts by industry in conservation and recovery, the imminence of any potential concern about public health lessens dramatically. In addition, we believe such international control by itself would provide the necessary incentive to develop and test environmentally safe alternatives, given a realistic timeframe. Forced reductions are not needed.

A major concern that we have with the UNEP proposal, as reported, is on the timing and magnitude of forced reductions following a production cap at or near existing levels. Forced reductions in the EC can be easily and quickly achieved because a substitute for one of their major uses, aerosols, already exists. The United States banned aerosols in 1978, an action not followed by most European nations. Forced reduction in other uses in the United States simply cannot be achieved in this timeframe because substitutes are not available and reductions, if implemented, would cause severe economic dislocations.

Aside from the ongoing conservation and recovery efforts, the only near-term alternate to CFC's is to return to the use of such chemicals as ammonia, sulfur dioxide, methylene chloride, and hydrocarbons. All these chemicals represent serious offsetting health, safety, environmental, and energy loss properties.

The invitation to testify asked us to address the availability of non-ozone-depleting substitutes for fully halogenated CFC's. At this time, we have no substitutes on the shelf and ready to go. Since 1974 we have studied approximately 65 compounds as possible substitutes; only three major candidates remain. Of these three, FC 134A and CFC 123, offer the best chance for marketplace acceptance and commercial success; 134A would have as its primary use a substitute for 12 in mobile air-conditioning; 123 would have as primary uses a substitute for 11 in foam blowing application. It is by no means certain, of course, that they will be successful.

These two compounds, coupled with the ongoing recovery and conservation efforts in 113 could reduce the usage of fully halogenated CFC's in the United States by between 25 and 40 percent. However, it should be stressed that any surviving candidate that turns out to be a satisfactory substitute will still require seven to ten years before it might be commercially available. The reasons are described in detail in our written testimony.

Mr. Chairman, members of the committee, one of the key questions that we understand you were seeking was to answer why the producers have not proceeded to commercialize the substitutes. Quite frankly, the market has not demanded substitutes.

During the time when the aerosol ban was being considered and went into effect, the projected rate of ozone depletion was extremely high. As a nation, we took action and banned aerosols. Within a few years of the ban, new scientific data was examined by NAS, the National Academy of Sciences, and the perceived threat to the ozone layer was reported to be not as great as previously thought. Even today, the debate continues. As a result of this lessened concern, the market for substitutes was simply not there.

Mr. Chairman, the real question is: What incentives are needed to spur development of alternates? We believe that limiting the growth rates of CFC's to at or near the 1986 levels is sufficient incentive. From a business perspective, the reason is simple: Such a control actually represents a significant reduction in supplying future demand, which could grow at three percent a year.

If sufficient development time is available, if there is a real need for the product and it is safe and effective, we can expect to spend the $50 million more required and be reasonably certain of a fair return on our investment. During this development period, we would expect the cooperation of our Government to be sure that foreign producers did not benefit from their late exit from the aerosol market and flood the United States with available product.

In summary, we believe an international agreement on this global issue is the only solution that will provide real environmental protection and will cause the least economic disruption. Unilateral United States action would provide only limited environmental protection while making United States industry less competitive. Timing is the key. Since there is no imminent danger, an international agreement limiting the growth rate of CFC's at or near the 1986 growth levels will by itself further mitigate any potential atmospheric problems and provide the necessary incentives to develop alternate compounds. Please be assured of our deep concern with the issue of ozone depletion and our desire to be responsive.

We know that many in Congress share our desire to expedite the development and commercialization of acceptable substitutes. Working together, we believe this is an achievable goal. Thank you.

Senator BAUCUS. Thank you, Mr. Traflet.

Mr. Farber?

STATEMENT OF HUGH FARBER, THE DOW CHEMICAL CO., MIDLAND, MI

Mr. FARBER. Thank you. I am a consultant to the Dow Chemical Company on this issue, and I am here representing their interests. I appreciate the opportunity to comment to the committee on a very important and extremely complex set of issues, as you have already heard from a variety of participants today and yesterday as well. We certainly share the concern that necessary and prudent steps be taken in a timely fashion to address this very important issue.

It is a very complex set of issues and concerns that are faced as you go about the process of trying to find alternative technologies or chemicals to carry on with some of the industrial needs and the home needs of the materials now being discussed. I think some of the factors that you have to consider are sometimes not considered when a major issue like ozone depletion is looked upon by some of the committee people and their staff perhaps, and thus I want to call these to your attention. You have heard some of it already—the very concern that toxicity and worker safety, which are two major or sub issues, flammability and the air pollution characteristics of whatever alternative technologies may be deemed acceptable be considered as you go about the process of looking at the timing and the degree of control might be necessary on things like CFC's.

In reality, of course, Dow doesn't produce CFC's. We are major users. We do produce carbon tetrachloride, which is used to make the CFC's, and more important for the written portion of the testimony which I have prepared, we are producers of both methylene chloride and methyl chloroform, two other chemicals which differ considerably from some of the CFC's but are included and named in two of the proposed pieces of legislation in the Senate.

Therefore, I would just like to discuss briefly the need to look at these other characteristics of materials as you look at the alternatives that might be available for these specific chemicals—methylene chloride and 1,1,1-trichloroethane, (or methyl chloroform).

These two chemicals have low ozone-depletion potentials. Indeed, methylene chloride is low enough that it has never been ranked on the scale, as far as I know. Methyl chloroform is higher, falling more in the range of perhaps some of the alternatives that may become available in the future, and CFC 22, which is an alternative for some uses today.

The exact range of these, I will call them, ozone depletion factors is not a precise determination for materials with intermediate residence times in the atmosphere. It depends on modeling, which is an imprecise art and can be better explained in terms of its degree of imprecision by someone other than myself.

However, modeling is a very difficult thing to conduct in a precise fashion, and therefore you shouldn't be looking at numbers of more than one significant figure at the maximum for cutoff concepts when it comes to what do you worry about and what don't you worry about in terms of timing for control needs.

Actually, low ozone depletion potential materials are really preferred chemicals at this time, including methylene chloride and methyl chloroform and CFC 22. They have what I call a correctability factor. That means that if there is found to be a serious ozone depletion occurring, actually measured in the atmosphere, the materials that have been emitted—these kinds of materials, if they have been emitted—are with significant reductions in emission basically removed from the atmosphere before they continue to build up and transfer to the stratosphere where the stratospheric ozone can be depleted. I think that is a very, very important point to keep in mind.

I am just about done with this. I guess the main comment is that there is a lot of complexity to the issues that need to be assessed, and we can't treat ozone depletion as an issue all by itself. It's not possible to solve the ozone depletion issue in this country by ourselves, which is one part of it, but also it's not possible to solve it without thinking about the other ramifications both environmentally and healthwise of the other technologies that you think may help solve the problem.

Thank you for your attention. I would be glad to answer questions.

Senator BAUCUS. Thank you, Dr. Farber.

Well, we got halfway through. There is a vote going on now. I will have to go to the Senate floor. I will be back in 10 minutes, and we will take another crack at this. Thank you very much. We will recess for 10 minutes.

[Recess.]

Senator BAUCUS. The subcommittee will come back to order.

Mr. Jeansonne, why don't you proceed?

STATEMENT OF ROBERT L. JEANSONNE, VICE PRESIDENT AND GENERAL MANAGER, DIVERSIFIED PRODUCTS, KAISER CHEMICALS, CLEVELAND, OH

Mr. JEANSONNE. Thank you. Mr. Chairman, good morning. I am a vice president of Kaiser Chemicals, a division of Kaiser Aluminum and Chemical Corporation. Thank you for the opportunity to be with you today.

We produce three chlorofluorocarbons, or CFC's: CFC 11, CFC 12, and 22. These products are produced at Gramercy, Louisiana, and they are sold to the refrigeration, air conditioning, foam insulation and packaging industries. We have been concerned about the CFC issue since 1972. We have closely followed the scientific, economic, and regulatory factors underlying this issue.

Senator BAUCUS. If I could, Mr. Jeansonne, ask you to summarize your statement in 4 minutes. We will go to Mr. Turner in 4 minutes. That is 8 minutes, because unfortunately there is another vote going on in 8 minutes and I will have to leave again.

Mr. JEANSONNE. All right, sir. I believe I can do that.

Senator BAUCUS. If you can, summarize in 4 minutes each, please.

Mr. JEANSONNE. We are concerned about any cutback in CFC production. We strongly believe that if CFC production and use are to be regulated, this must occur under a worldwide agreement rather than through unilateral action.

We respectfully urge that you consider three factors in determining your immediate future actions: First, please take no unilateral action. Second, consider CFC 22 as part of the solution and not part of the problem. Third, please recognize that restrictive legislation can have unforeseen and unexpected consequences. For example, we cannot assume that safe substitutes will be employed. If development of safe CFC substitutes is delayed or if the cost proves to be too expensive, the use of less safe substances could become as prevalent as they were 50 years ago.

Import restrictions designed to control or prevent competitive advantages to non-participating foreign countries could be virtually impossible to administer and could have unexpected and undesirable side effects. I address this issue in my written statement, and I commend it to you for your consideration.

We believe that this situation can be dealt with in a reasoned, constructive manner. Our basis for saying this is that at current production levels, CFC's pose no long-term hazards. Atmospheric modeling calculations indicate that if worldwide production of CFC's 11 and 12 continues at present rates, steady-state ozone depletion will be insignificant and greenhouse effects will be very small. There is no reliable evidence that CFC's have caused any decline in global ozone at present levels.

Third, even if CFC production increases, there will be adequate time to validate models and to develop replacements during the next two decades. Potential replacements for CFC 11 and 12 have been identified. They include CFC 22, which is produced in commercial quantities now, and it can be substituted for CFC 11 and 12 in many applications, although at a cost penalty.

The other most promising candidates appear at this time to be CFC 123 and FC 134A. Neither is commercial. Both contain hydrogen. One contains chlorine, the other one does not. Both would be much more costly and difficult to produce than the CFC 11 and 12.

We recommend to this committee that they encourage a continuing international program of research and monitoring to ensure that these long-range effects are thoroughly understood. We recommend an equitable program that would allow us to compete on a level playing field. We further recommend that you provide a requirement for the EPA to formulate the environmental impact standards for replacement compounds and to establish procedures for clearance before sizeable quantities of new products are released to the atmosphere.

In conclusion, we strongly urge against regulations leading to a phaseout of currently used CFC's. Forced-reduction cutbacks are not needed for environmental protection. Even more detrimental are agendas for unilateral U.S. production cutbacks in excess of those agreed to by all other nations. In this case, it would require the users or domestic manufacturers to compete, and exports would be at a decided disadvantage in export competition.

This concludes my summary of those topics covered in my written statements. Thank you for this opportunity to express our views.

Senator **Baucus**. Thank you, Mr. Jeansonne. I appreciate your holding that down to 4 minutes.

Mr. Turner?

STATEMENT OF MARSHALL TURNER, VICE PRESIDENT OF MANUFACTURING, RACON, INC., WICHITA, KS

Mr. **Turner**. Thank you, Mr. Chairman. I can probably do mine in about three.

Racon's position is that the current bills before the House and Senate are too aggressive in their short time frames for the phaseout. I think it prudent to cap production of R-11, 12, and 113 at current levels, but scientifically unjustified to include phaseouts within 6 to 8 years with no compatible alternatives to implement now. I believe R-22 should be considered as part of the solution and not identified as part of the problem. It is easy to get carried away with the hype of the moment, but it will not harm the environment if a prudent course of action is adopted, one where a coordinated effort for control of releases and development of alternatives between users and producers are encouraged.

Racon is a producer of chlorofluorocarbons 11, 12, and 22. We do not produce any of the other chemicals listed. One hundred percent of Racon's yearly sales are in CFC's. Chemical substitutes besides R-22, most commonly known for refrigeration and air conditioning, are ammonia, ethylene, sulfur dioxide, and natural gas. Racon produces R-22 but does not produce or supply any of the others.

Historically, for refrigeration, ammonia, ethylene and SO_2 were chemicals of choice due to availability, but were displaced from the marketplace by CFC's. The main reasons for displacement were toxicity, workplace hazards associated with use, and efficiency of application. Usage of these chemicals where the general public would be exposed could have the potential of a major, immediate catastrophe.

Racon has been a member of the fluorocarbon program panel of CMA since its inception, supporting the scientific investigation of this CFC ozone issue. We have developed the capability to produce additional R-22 if needed. As I said previously, I think R-22 can be a viable near-term alternative for substitution. Racon has developed a superior leak detector for closed-system refrigeration and air conditioner applications, and we continue to monitor developmental activities associated with the longer-term alternatives.

It is premature for me to speculate on what chemical substitutes may be available in the future. Those getting the most press right now include CFC 123 and 134A, but others you have heard are much closer to that development. To my knowledge, none of the alternatives other than CFC 22 are commercially available today, nor do they have a proven production route or demonstrated acceptable toxicity.

Surely, if production is capped and a use allocation method is not mandated, prices for current CFC's will rise to the level necessary to supply the demand of the least cost-sensitive user. Assuming that alternatives are available at equivalent costs, the price demand for the various applications will equilibrate. If alternatives are not available or if they are not cost-justified, businesses will close and jobs will be lost.

Aggressive unilateral action by the U.S. seems extremely shortsighted to me. Threatening gestures by the U.S. appear to be counterproductive to meaningful international negotiations. The accused chemicals are efficient in their applications and relatively safe in the workplace, and if CFC's do affect ozone, the solution is international in scope. Unilateral action will have little or no impact upon the ultimate effect.

The implementation of plans to control CFC's will definitely have an impact on lifestyles. If the very short time frames proposed are implemented without acceptable alternatives, there could be major disruptions, but I am sure you will hear considerably more about this subject tomorrow from the experts, those users of these chemicals.

Thank you for the opportunity to present this statement.

Senator BAUCUS. Thank you, Mr. Turner.

Both Senator Symms and Senator Durenberger are here.

Senator Symms, do you have a statement?

OPENING STATEMENT OF HON. STEVE SYMMS, U.S. SENATOR FROM THE STATE OF IDAHO

Senator SYMMS. Mr. Chairman, yes, I do have a very brief opening statement, and I would say I am disappointed that it turned out that we have all this action on the floor this morning that competes with this important hearing. But I do thank all the witnesses that are here.

I am glad to see the subcommittee in the process of gathering information on ozone depletion. It concerns me that the educational hearings that we are having follow the introduction in the Senate of what I would consider to be a piece of legislation that is excessively oppressive and regulatory in nature. So I hope that it leads one to think—and I hope that I am wrong about this—that these hearings are here less to educate and more of a forum for padding up already advanced proposals.

Nevertheless, the testimony presented has been very interesting. I note, for instance, that the witnesses from the scientific community for the most part lack any conclusive evidence of a known and quantifiable relationship between current trends in the atmospheric ozone and the manmade chemicals such as chlorofluorocarbons, CFC's. At most, some support was voiced for several models that suggest such a relationship.

But models are not conclusions; they suggest possibilities. They do not provide us with the irrefutable facts upon which to base regulatory decisions. The chemical equation wherein CFC's can be shown to add to the ozone deterioration has been a known factor for more than a decade. But yet what exactly is the extent of that chemical reaction in the stratosphere has not been established.

In fact, at least one expert witness had the professional integrity to qualify any finding, advising caution in the interpretation of long-term trends in the total ozone, and pointing to evidence that the Antarctic ozone fluctuations can be dynamical in origin.

He also expressed his expert opinion that the chemical trends due to CFC emissions cannot be confidently determined. My own research on this issue leads me to believe that deforestation of the tropics may be a significantly greater concern when considering the global atmosphere. It could be that the Congress, Mr. Chairman, should take a month to investigate what is happening in the Amazon and maybe we would do less damage to the public if we all went down there for a meeting.

I am surprised that the legislative proposals have not suggested and addressed the issue more adequately but instead focus on regulation of chemical compounds which are at most partial culprits. In fact, some of the regulatory proposals introduced in the Senate would remove from the use of compounds such as CFC 22, known to have only minimal impact on atmospheric ozone. The impracticability of banning what would otherwise be an excellent alternative again adds to the impression that these bills have been introduced for political publicity purposes and not as a scientifically derived response to any real problem.

Now, I don't say that to impugn anyone's motives, because I think it is important that we address the issue and maybe the only way to do that is to introduce the legislation, and I think we have all done that, and certainly I have done it on different issues to focus people's attention on what may or may not be a problem.

Mr. Chairman, perhaps this subcommittee forgets that we are deliberating about people's livelihoods. As Chairman Baucus said in his opening statement Tuesday, there is not a person in this room who does not receive the benefits of CFC's through its use in plastics, refrigeration, or air conditioning. And an onerous and ill-advised regulatory action by this Congress can put thousands of people out of work and lower the standard of living of millions.

So I urge my colleagues to pay close attention to the potential results of these legislative proposals. I would hope, as one member of the committee, that it would be our intention to move very carefully, methodically, and slowly towards any answer in terms of legislation to this problem.

I would consider that we are still at the infancy of studying this, and there is a great deal of more work that needs to be done before any serious effort to pass legislation should come about.

Mr. Chairman, I thank you very much for your indulgence.

Senator **Baucus**. Thank you, Senator, very much.

Mr. Mandell, we will get to you when we reconvene the hearing. We will recess again for about 10 minutes.

[Recess.]

Senator **Baucus**. I again apologize for the inconvenience this is causing the witnesses. I do not know how many more votes like this there will be. We will just have to do the best we can.

Dr. Mandell, you are next.

STATEMENT OF HARRY C. MANDELL, JR., SENIOR VICE PRESIDENT, PENNALT, INC., PHILADELPHIA, PA

Mr. **Mandell**. Thank you, Mr. Chairman. I am Harry C. Mandell, Jr., senior vice president, Pennalt Corporation, in Philadelphia. We are pleased to have this opportunity to present a summary of Pennalt's involvement in the chlorofluorocarbon industry. Pennalt is a manufacturer of CFC's 11, 12, 22, and 142B, having a market share of between eight and ten percent of the total domestic production of CFC's. Pennalt does not produce 113, 114, 115, halon, or chlorinated solvents.

Our policy regarding the CFC ozone depletion issue is as follows: First, we support the premise that there can only be a global solution to the problem. The United States uses only 30 percent of the CFC's produced in the world. We are, therefore, opposed to a unilateral activity on the part of the United States that might reduce our production. Such an action would not provide a long-term solution to a problem that is clearly worldwide in scope. In addition, it would inevitably damage the competitiveness of United States companies in many industries.

Secondly, Pennalt joins with other members of the Alliance in calling for a global cap on CFC production at 1986 levels. We believe that such a global cap would constitute an appropriate and immediate action, pending continuing further scientific study of the stratosphere. We believe this testing must continue, and any decision to modify a cap must be based on the results of ongoing research.

There is also, of course, the possibility of solving the problem through the development of replacement products. As the other industry panelists have noted, CFC 22 can generally be regarded as part of the solution and not part of the problem. Every substitution of 22 for 11 or 12 accomplishes immediately an effective 95 percent reduction in potential ozone damage.

Another Pennalt product, CFC 142B, is even less ozone-damaging than 22. A blend of 22 and 142B was developed by Pennalt as a substitute for CFC 12 for the aerosol market and was introduced in 1978. Toxicity testing was completed in 1983, and Pennalt has marketed this blend to the aerosol industry since 1984. This blend could also be a substitute for many cooling and refrigeration applications presently using CFC 12.

Although this 60-percent/40-percent blend is nonflammable, pure 142B is rated as moderately flammable, and this has caused concern with some end users. A word of explanation is in order. If there were a slow leak from a blend of 142B-22 that would permit 22 to leak out faster than 142, the remaining mixture would become more concentrated in 142B and eventually might become flammable. We think this is an unlikely circumstance, but we are working on what seems to be an acceptable technical solution using a third component added to the blend.

Pennalt has sent samples of 142B and blends of 142B with 22 to customers in the automotive, polystyrene, and appliance industries. The anticipated selling price of this blend is $1.50 a pound, assuming high levels of production. This compares with the present CFC 12 price of 60 cents a pound.

Pennalt's present capacity for 142B is limited. It is equivalent at present to ten percent of the U.S. production of CFC 12. A new 142B plant would take 3 or more years to build, at a cost in excess of $30 million. In addition. Pennalt could conceivably convert some of its existing manufacturing facilities for other CFC's to 142B. Because we believe that this substitute for CFC 12 is commercially available, Pennalt has spent proportionally more of its R&D budget on this 142B answer and proportionately less on other CFC substitutes.

In summary, we think it is important to emphasize that the American chemical industry has in the past effected transitions from the use of substances which have been identified as of concern from an environmental, health, or safety standpoint. It is seldom possible to find replacement materials which are identical in all respects. There will always be different costs, different handling and application properties, different physical and chemical properties. But under our free enterprise system, producers and consumers can make a successful transfer from those of the chlorofluorocarbons which may be most damaging to ozone.

What industry needs, however, is a reasonable period of time and a reasonable opportunity to make these changes. A sudden and unilateral imposition of restrictions would injure us economically versus our global competitors and impair both our incentives and our ability to develop useful alternatives.

Thank you.

Senator BAUCUS. Thank you very much, gentlemen.

As I listened to all of you, I sense that most of you believe, and your companies believe, that CFC production does probably have an adverse effect on the stratospheric ozone layer but it is really a matter of degree.

Is that a fair statement, or does anybody disagree with that statement? Does any one of you disagree with that summary of what I take your position to be? What I heard you say is: no effect.

Mr. JEANSONNE. At present levels. Now, we certainly concede that at two to three to five times worldwide emission levels, that there would be an effect. We believe, on the basis of information, the technological information, the model studies that are available to us and, I assume, to everyone in this room, that at present the effect does not exceed the background or the static of the information that we have. That's our belief.

Senator **Baucus**. Is it a fair summary, though, do you think, at present levels there is some degree of damage?

[Chorus of noes.]

Senator **Baucus**. You all believe that?

Mr. **Blanchard**. Growth from the current levels over an extended period of time.

Senator **Baucus**. All right. Now, your basic——

Mr. **Turner**. May I have a chance to respond?

Senator **Baucus**. Sure. But let's assume growth at, what, 3 to 5 percent, is that a fair growth rate, and are you all saying that a 3 percent growth rate of CFC production will not be enough of an adverse effect on the ozone layer to warrant any Governmental action? Is that what you're saying?

Mr. **Turner**. No, sir.

Senator **Baucus**. What are you saying?

Mr. **Traflet**. We are saying that if you had growth in the 1 to 3 percent level, you'd feel very safe.

Senator **Baucus**. Do you all agree with that statement? Dr. Mandell, you're shaking your head.

Mr. **Mandell**. As an old chemist, I would have to say that absolute scientific proof is often a very, very difficult thing. In this particular case, I think there is enough evidence to warrant a cap and further study.

Senator **Baucus**. Do you believe there is enough present evidence to warrant a cap?

Mr. **Mandell**. Enough suspicion, and reasonable doubt to warrant a cap and further study, but not more than that.

Senator **Baucus**. Mr. Turner?

Mr. **Turner**. This basic theory has been around since 1974, and there has been an awful lot of effort to either prove it or disprove it, with no absolutes on either side. It's all an issue of unknowns, and I think in the face of those unknowns and the continuing growth of these compounds in the atmosphere, that it is prudent to cap it at about current levels and then look and see to develop the alternatives to get more scientific evidence.

Senator **Baucus**. Do the rest of you agree with that statement?

Mr. **Turner**. I concur.

Senator **Baucus**. A cap, at what level? Do you cap at a freeze; are you talking about a freeze or are you talking about a limit to current growth rates.

Mr. **Turner**. A cap.

Senator **Baucus**. A freeze?

Mr. **Jeansonne**. At around current levels.

Senator **Baucus**. Do you all agree to that?

Mr. **Jeansonne**. No, sir, let me say I at least partially agree, a cap on 11 and 12. Now, I think an important point here is 22——

Senator **Baucus**. But basically a cap on 11 and 12?

Mr. **Jeansonne**. Yes, sir.

Senator **Baucus**. I understand. Now, to what degree do you have faith in this recent study that will begin roughly August 10 or August 23 to look at the Antarctic hole? A lot of folks have testified that that is going to be a very thorough study to attempt to answer a lot of questions as to the degree to which the ozone depletion in the Antarctic is due to chemical processes or dynamic theories or whatever. I am wondering the degree to which you all have confidence in that study and the degree to which it is going to answer a lot of these questions.

Mr. **TRAFLET**. I think the Antarctic is a peculiar part of our world, has conditions very different than anywhere else in the world. You might find things there that don't apply anywhere else.

Senator **BAUCUS**. So you don't think it makes much difference what they find?

Mr. **TRAFLET**. I really think it's a unique situation in the Antarctic and you can't necessarily extrapolate Antarctic data anywhere else.

Senator **BAUCUS**. All right. To what degree do any of the others agree with that?

Mr. **TRAFLET**. In fact, Senator, even if you were to find that there was no problem in the Antarctic, that wouldn't mean the rest of the world was safe from uncontrolled emissions.

Senator **BAUCUS**. Let see if the others have confidence in that study.

Mr. **BLANCHARD**. I doubt that it will be definitive.

Senator **BAUCUS**. Well, nothing is definitive. I am asking the degree to which——

Mr. **BLANCHARD**. Pardon?

Senator **BAUCUS**. To what degree do you think that study is going to answer some of these questions? Have you looked at it?

Mr. **BLANCHARD**. I think it's very improbable that it's going to answer all these questions. I think it's going to take studies of that type over an extended period of time before we fully understand the science.

Senator **BAUCUS**. Let me shift gears here. Help me understand what happened with the aerosol ban; that is, the degree to which the United States was the producer of chlorofluorocarbons, aerosols, how much of a problem that was to industry, what the costs now of the alternatives are, and so forth? Could someone run through that for me, please, in answering these questions?

[No response.]

Senator **BAUCUS**. Is there anyone here who is familiar with the ban?

Mr. **BLANCHARD**. Well, first of all, in the case of aerosols—and let me just check—there was about a 600 (subsequently corrected to 450) million pound market in the United States for chlorofluorocarbons in aerosol applications. When the threat of regulations of aerosols occurred, the users of aerosols immediately looked for alternate methods of either performing the aerosol function or, more likely, applying products in a non-aerosol fashion.

As a result, by the time that the legislation and the regulation went into effect in 1978, the market had all but disappeared. This resulted in very significant rationalization on the part of U.S. producers of chlorofluorocarbon production.

It had no impact on the European producers. Only two countries, I believe, Scandinavian countries, also followed with aerosol control.

Senator **BAUCUS**. What is a substitute for CFC's in aerosols?

Mr. BLANCHARD. Some hydrocarbons are in use.

Senator BAUCUS. What is the relative cost of hdyrocarbons compared to CFC's in aerosols?

Mr. BLANCHARD. I am sure they are very, very inexpensive. They are also very flammable and therefore have certain risks associated with them, chlorofluorocarbons did not. I don't believe the aerosol market ever retained its original size. Roll-on antiperspirants and so forth replaced the sprays.

Senator BAUCUS. What I am trying to determine is the degree to which the substitute of hydrocarbons for chlorofluorocarbons caused dislocation in the industry or in any other significant way. Can anyone address that question?

Mr. BLANCHARD. In the chlorofluorocarbons manufacture it had a significant dislocation because we shut down facilities to produce them. In the aerosol industry I am not prepared. I think that question should go to the users in their panel. But clearly, many of them shifted away from aerosol forms to other forms of marketing their products, and as a result you had that kind of a dislocation.

It's not quite comparable, however, to relate aerosols to refrigeration, to cooling, to these other applications, because you're dealing with a use that was easier to have alternate means than you have in refrigeration. The safety factors are quite different.

Mr. FARBER. If I could comment a little bit on some of the applications of that switch in the aerosol industry, because we followed it within Dow from a substitute point, we had methylene chloride and methyl chloroform available for some uses in aerosol products.

But one of the things that we observed happening as people scurried around trying to find alternatives was dislocation of aerosol manufacturing companies to some extent, as they had insurance problems or flammability problems with the local Government. With the conversion to the flammable materials, in a relatively short time, but certain observable rash of fires took place in some of these plants as they made that conversion to the hydrocarbon materials. I don't have any numbers on that. But those are the observations that we made as we followed that trend from CFC in aerosol to more complete hydrocarbons.

Also remember that hydrocarbons were already competing with CFC's in all these aerosol uses at that time, so the technology was more or less there to do that.

Mr. MANDELL. Mr. Chairman, as a result of the aerosol regulations, Pennalt Corporation closed a relatively new fluorocarbon gas plant in the State of New Jersey. It was only seven years old. So there was a considerable capital writeoff as well as a loss of earnings.

Senator BAUCUS. Do any of you think that that was a wrong decision for this country to make; that is, to ban CFC's in aerosols?

Mr. MANDELL. Yes.

Senator BAUCUS. You think it was?

Mr. MANDELL. I think it was wrong in the sense that it had essentially, I am sure, no impact or very little impact on the global ozone situation, and it had a substantial economic impact on American industry.

Senator BAUCUS. Just for my information, what percent of CFC production is used in the aerosol cans at the time, roughly?

Mr. **Blanchard**. Twenty-five percent.

Senator **Baucus**. Twenty-five percent?

Mr. **Blanchard**. Yes.

Senator **Baucus**. So I am both curious, Dr. Mandell, if it was 25 percent, how does that square with your conclusion that there should be a cap?

Mr. **Mandell**. I am thinking that the U.S. is a 30 percent consumer of the world's total production of CFC. If it reduced the aerosol portion of that segment to zero, that is only 25 percent of 30 percent of the total world output of chlorofluorocarbons.

Senator **Baucus**. Your assumption is that there is an adverse effect, that chlorofluorocarbons do have an adverse effect on the ozone layer generally, worldwide?

Mr. **Mandell**. It's not my assumption. I said previously that I believe that the weight of the evidence gives a reasonable suspicion.

Senator **Baucus**. I have taken up my time.

Senator Chafee?

Senator **Chafee**. Mr. Chairman, I would just like to get on the record, if I could, the statistics on this particular subject. My statistics show that in 1985, of the 100 percent of CFC's used in the world, 19 percent are aerosols. The United States is the largest producer, and in the United States the aerosols are not 19 percent as the world is, but in the United States they are 3 percent. So I think we can say from that that if the United States had not dropped its aerosols down as we so dramatically did, that the number of millions of pounds of aerosols in the United States would be very substantial.

We were at a half a billion pounds in 1974, and we are at about 25 million now. So that is a little bit of progress. The point is that our getting out has reduced the total CFC's in the world very substantially; there is 475 million pounds.

Yes, Mr. Farber?

Mr. **Farber**. Could I respond on the other side of that coin? I think if the United States—Senator Baucus asked if the U.S. legislation that banned the aerosols in 1978 was a good piece of legislation and should we have done it—scientifically I don't think I have an answer for that. But I think looking at the global situation which Senator Chafee brought up, if the United States had somehow succeeded at that time in convincing the rest of the world that this kind of action was necessary, instead of going on a unilateral basis, we would be looking at twenty percent less or whatever that number was you quoted, CFC 11 and CFC 12, in the atmosphere today, and we would have less concern about that total amount.

Senator **Chafee**. If we had succeeded in persuading everybody.

Mr. **Farber**. Well, the rest of the major users and producers.

Senator **Chafee**. That's right.

Mr. **Farber**. That's right.

Senator **Chafee**. Yes. I certainly agree with you. I think that I certainly am dedicated to making sure that if we go into further bans on U.S. production of CFC's, that we enacted into our trade policy and be really tough on others. For instance, to refuse to import chips that are clean. If we banned cleansing of our chips with CFC's, then ban the import of any chips that are cleaned with CFC's. You know, there are some verification and monitoring problems with that, but it can be done. I just don't think we've used our full power as the major trader of the world to the extent we might have.

But let me ask you a couple of other questions. I apologize that I was not here for all of your testimony. But in summary, it is my belief and my understanding that everybody said don't move ahead unilaterally, move ahead in an international agreement, just like you said, Dr. Farber, in connection with aerosols we should have done.

But then some of you are certainly saying the proposed agreement goes too far, reductions aren't needed, a limit on growth will suffice. Is that true?

Mr. **JEANSONNE**. Yes, sir.

Senator **CHAFEE**. How many say no reductions are needed?

Mr. **MANDELL**. I do.

Senator **CHAFEE**. All right. Well, there is one out of five.

What do you say, Doctor? No reductions needed? Yet that is what the proposed agreement says. It has some reductions. Would you oppose that?

Mr. **BLANCHARD**. Immediate reductions, yes.

Senator **CHAFEE**. Well, how about at the end of 6 years?

Mr. **TURNER**. What alternatives do we have in that time?

Senator **CHAFEE**. What do you mean what alternatives?

Mr. **TURNER**. Well, you are asking me for concrete responses. I can't answer that. The cap does take some of the unknown out of the issue. It doesn't allow these chemicals to continue increasing. We don't know all the answers. The scientists don't know all the answers. We do need some time to develop alternatives. We do need some time to see what the impact of these chemicals are.

Senator **CHAFEE**. I have one objection to what is being said here. That is that it is being portrayed as this is a matter of great scientific doubt, that there is a fringe over there that says these CFC's are harmful, the chlorine in our atmosphere is bad, but there is another great body of opinion over here that says there is no problem at all.

If you could produce a reputable scientist that will say that these things are not having the disastrous consequences that we foresee, we would like to hear it. But we didn't have any testimony to that effect. You can say we stacked the deck, well, I don't believe we did. If you can produce some scientists that will speak to the other side, I would be interested. Am I wrong?

Mr. **JEANSONNE**. Senator, unfortunately, I did not attend yesterday's testimony, but I did listen to the testimony this morning. I did hear the testimony that at a 3 percent growth rate, which I guess in the next century would result in CFC emissions at a level of five times present, we could expect over this 100-year period or 90-year period, whatever it was, one million additional cancer deaths.

Now, the testimony I did not hear is how many additional cancer deaths would you expect if you had a cap and you did not enlarge it and there was no discernible difference in ozone. So I guess our position is that it is a matter of risk assessment and it's a matter of degree. And certainly, if we are looking at a two-to-three-time increase in CFC emission, a million deaths over a hundred years turns out to be 10,000 deaths a year, which is lot of deaths. And that's one thing. But if there is no testimony to indicate that if we stay at present levels there is anything more than a very slight change in the ozone level, that would be a different situation—and that is the one I am referring to.

Senator **CHAFEE**. Well, the testimony we have is that these gases have a very long life, that obviously, it's cumulative. The more you release, the more there is. It just doesn't disappear. And now we are reaching a situation where the atmosphere is overladen, and these consequences are occurring.

Mr. **JEANSONNE**. Yes, sir.

Senator **CHAFEE**. And the time to blow the whistle isn't 5 years from now, it doesn't seem to me; it's now.

Mr. **BLANCHARD**. Senator, may I comment on this?

Senator **CHAFEE**. Sure. We're not here to beat up on industry, but we are concerned about this.

Mr. **BLANCHARD**. We have been very active in studying the ozone phenomenon. We do not question that the chemistry is operative. The real question over the years has been what is the effect of that chemistry in the stratosphere, the ozone layer and the increased incidence of ultraviolet radiation.

Our conclusions in looking at the situation last fall or last summer were that with the increased production levels and the current growth rates, our computer models that try to model the stratosphere, indicated that if we had a four to five percent growth rate over an extended period of time, another 30 or 40 years, that we could see a situation out there in maybe a 100 years that would have a sufficient reduction in ozone to cause us concern.

Recognizing that, we felt it was time to take a position to call for a limitation on growth because we believe it will require 20 to 30 years to effectuate a transition to alternate materials if they can be produced and if they're safe.

We also recognized that to do anything in a meaningful way, we needed international accord, not another unilateral action which simply decimates our industry. As a result, we recognized that there would probably be some compromise from a limited-growth scenario on the one hand, which we think is acceptable, to the positions taken by other groups and other scientists, incidentally, that there needs to be a very substantial immediate reduction.

We felt, though, that in the interest of an international accord, that a modest reduction or a phased program of production cap followed by modest production reductions could be an acceptable compromise if it led to an international protocol and agreement. We think this is the direction we are moving and we are encouraged with that, recognizing that part of the plan would be to continue to study the science. If the science teaches us as we move down this path, that we are being overly reactive and we can move much more slowly in reduction, we could respond to that. If it turns out that the science is teaching us, our understanding is optimistic and the situation is worse, we could accelerate the phaseout.

But this, I think, is important, that we wanted an international agreement, and I think to achieve that some compromise may be necessary.

Senator BAUCUS. I wonder if I might on that point of an international agreement; one of the threshold questions is the degree of harm caused by CFC's, and there is debate on that. I understand that. There is legitimate debate, and it is never going to be completely resolved because it's a complex question.

But let's assume that CFC production and emissions do cause considerable harm in the depletion of the ozone. Let's just assume that for a moment. If that's the case—I am not saying it is—but if that is the case, then we go to the next question; that is, the appropriate development of substitutes and the costs and the cost-benefit analysis of substitutes and so forth, and that is along with whether we have international agreement or not—that is does the United States go it alone or do we only act in concert with other countries?

But let's assume that we have established—I am not saying this is the case—but assume that the capacity is the first question of harm. So we go to the next question of substitutes and the costs and acting in concert—that is, does the United States go it alone?

What is your feeling about some kind of trade restrictions? Senator Chafee touched on a very important point; namely, why should the United States go it alone in developing substitutes, since they're costly and it's going to make us less competitive and we'd bear the burden of development costs? It's just not fair. Why should we have to do it all when those other countries are out there emitting CFC's and causing harm too? I understand that. It's a good point.

So for that reason, as Senator Chafee and others have suggested, let's say that other countries don't take advantage of us that we could put a tariff on or somehow limit and restrict the importation of either their CFC's or their products that utilize CFC's in this country so that it's all fair and square.

Now, what's wrong with that argument?

Mr. BLANCHARD. I would very much like to address that. And I would like to come back to the example that Senator Chafee used, which was the microchip in the electronics industry. To be sure, we could establish trade barriers, we could establish hurdles, we could put tariffs on and so forth to limit the importation of microchips or products produced from them that in any way have been produced with CFC's that we felt were harming the environment. Then that in our market may indeed create an opportunity to develop alternates for our domestic market.

But what we are going to do is to cut ourselves off from the rest of the world. We are going to isolate ourselves.

Senator BAUCUS. Why is that? Explain that.

Mr. BLANCHARD. Because our electronic products produced with higher-cost materials will be noncompetitive in the world markets and as a result, it won't be a matter where we will say, "Well, we're not going to import electronics from Japan, because they're using a CFC that we think harms the atmosphere." We are probably not going to participate in the markets that they're serving around the world who don't share our concern on CFC's.

So we not only have to limit the importation into the United States or tariff it, but we have to cause the rest of the world to say, "And, I won't do business with anybody that uses it either." I think without an international accord, we won't be successful there. And what we're going to do is to see not only our chlorofluorocarbon industry shrink and wither, but those important downstream industries that use our products find that their world markets are being closed out because of their noncompetitive cost position.

Senator **Baucus**. On that point, though, whenever—let's take the semiconductor action this country took. The United States imposed hundred-percent tariffs on the importation of Japanese semiconductors because our country made the determination that Japan was doing something unfair. It was dumping, not only in U.S. markets, but third-country markets, and there it also was denying access to American semiconductors into the Japanese market. That was a cost Japan imposed as an unfair trade practice.

Now, why is that different from another cost, another unfair practice; that is, developing a product on a more cheap basis. We have countervailing duty actions against a country that subsidizes its development of product. What's different? Why is it different for a country—let's argue Japan—say, to subsidize a product and the United States takes an action against a country that subsidizes a product, and in that case, compared to the other case where the subsidy is just because a country is not using non-CFC's? What's the difference?

Mr. **Blanchard**. I would say as the interrelationship between the United States and Japan is concerned, they may be quite comparable. But the fact that we put up a tariff barrier or a penalty on Japan for imports into this country I don't think affects how Japan is selling their products in the rest of the world.

Senator **Baucus**. Yes, it is. It is having that effect.

Mr. **Traflet**. May I comment on that? Senator, I think if you asked the textile industry or the shoe industry how effective we have been in enforcing the existing laws on trade or preventing foreign exports in dumping into this country, you would find that we are very ineffective at doing that. Even the Japan action just recently, despite all the desire of many people in Congress and many in the administration to have free trade, it is merely a slap on the wrist of the Japanese and really doesn't affect a very high percent of their products.

Senator **Baucus**. Senator Chafee?

Senator **Chafee**. Mr. Chairman, I have a question here from Senator Stafford, and I would ask if everybody would follow it rather carefully. November 30, 1983, the CFC Alliance told this committee the following, and this is an exact quote,

> Obviously, if analysis of actual measurements, such as ozone trend analysis, tells us a problem is developing, we should act.

Okay. Yesterday this committee heard from eight scientists whose professional careers are devoted to understanding this subject. Senator Stafford asked each of them whether an analysis of actual measurements indicated that stratospheric ozone had been depleted. Several of them answered with no hesitation whatsoever, saying, "Yes," the stratospheric ozone had been depleted. Two of them demurred, but none of them disagreed.

Senator Stafford then went on to ask them whether it is more likely than not that CFC's were the cause of the depletion. Only one of the eight disagreed. He thought the variations were natural.

This leads Senator Stafford to the following questions:

First, "Why are you today advocating a status quo with respect to CFC's when you"—meaning the Alliance—"said in 1983 that we should act if an analysis of actual measurement showed there was depletion of the ozone shield?"

Why are you advocating? That is his question.

Mr. **Blanchard.** One, we would agree with that demurring by one opposing scientist, in that our measurements and those of the NASA report of May 1986 show no persistent change, or trend in ozone.

But even accepting that, I counter with the fact the position that the Alliance and a number of producers took late last year in calling for a limitation on the growth of chlorofluorocarbons is indeed to a response, not that we have seen a change or that we accept we've seen a change, but in my mind on the basis of the continuing uncertainty that makes us uncomfortable. After 12 years of study, although we can't see a persistent trend or change, to me that uncertainty when we know that chemistry is operative is also of concern.

Senator **Chafee.** Thank you, Mr. Chairman.

Senator **Baucus.** All right. This is one of the costs of this job, going back and forth to vote. We do have another vote in progress. We do have more questions, because I think your panel is probably one of the key panels on this subject. We will vote, and we will come back as quickly as we can.

Senator **Chafee.** What we are going to do is we are going to go vote, but Mr. Shimberg is going to read two other questions, from Senator Stafford. He will act as Senator Stafford, "Senator Stafford-Shimberg."

Senator **Baucus.** Before Mr. Shimberg proceeds, I warn the witnesses that it is possible that there may be an objection to this committee continuing this hearing after noon. Under the Senate rules, technically, if a Senator objects to a committee holding a hearing 2 hours after the Senate convenes, then the committee cannot hold a hearing. We do not know whether a Senator will object or not. But it is possible that some Senator may object, so that we will have to conclude the hearing. You will find out in another 10 minutes.

Thank you.

[Recess.]

Mr. **Shimberg.** Dr. Blanchard, do you want to continue with that response for the record?

Mr. **Blanchard.** I beg your pardon?

Mr. **Shimberg.** Will you finish with your response? Do you want to continue? Shall we move on?

Mr. **Blanchard.** No, I was finished. Thank you.

Mr. **Shimberg.** Mr. Traflet, could you respond to the first part of the question?

Mr. **Traflet.** Will you repeat it, please?

Mr. **Shimberg.** Sure. The first part of the question is, "Why are you today advocating the status quo with respect to CFC's when you said in 1983 that we should act if an analysis of actual measurements showed there was depletion of the ozone shield?"

Mr. **Traflet**. Well, I will get back to the same NASA quote, if you would like, that same publication of May 1986. It said that even if there were a 1.5 percent growth, there would be less than a 3 percent reduction in 70 years in the ozone layer. I think that somebody mentioned before, you are dealing with static in the measurements when you're talking about these levels, being concerned about 3 percent in 70 years. I really don't think we are at a point of concern yet.

But let me assure you, though, that we are recognizing the political ramifications of the situation as well as our own personal concern, and we are working for substitutes. We have work going on trying to find substitutes, looking at existing materials and how they might be used by themselves or in blends, to substitute for 11, 12, and 113, and we are working on the materials we mentioned in our testimony, trying to find substitutes, and we would like to bring them out as soon as we can.

We are going down the road, spending the money, trying to bring out a material as quickly as we can. We still are calling for action through controlled growth, and when we say controlled growth, we are talking 1 to 3 percent a year. We think that is a prudent level of growth and giving the industry time to develop substitutes.

Mr. **Shimberg**. Thank you.

Dr. Farber?

Mr. **Farber**. Well, as I said earlier, we are not producers of CFC, and I am talking a little out of school on that. I think our chemicals aren't really intimately involved in the issue. But I want to respond anyway because I think from my scientific review of what has been published by the analytical scientists, there has not been a depletion of stratospheric ozone observed that has been related to CFC's. There are natural drifts in ozone concentrations, and what has been seen—I think Bob Watson said it very clearly earlier—could easily fall within the range of natural variations with no observed trend yet defined by the information available.

There is going to be additional work done, I am sure, and already planned to conduct those kinds of experiments, and I think there will be some answers coming out of that over the next few years.

The other thing is that there are a lot of uncertainties and potential concern on the part of industry—you have heard it from everyone here—with the other issues that surround this issue. Therefore, there has been a response from industry. That is that more or less, at least on the global basis, some agreement that some kind of cap on production, whatever that turns out to be found most acceptable, is called for based on uncertainties and potential ozone depletion concerns, not on observed ozone depletion to date.

Mr. **Shimberg**. Thank you.

Mr. **Jeansonne**. Mr. Shimberg, I would like to respond from a slightly different viewpoint. The question really is the amount of ozone that intervenes in the column between you and the rays of sunshine. The ozone is what is absorbing the ultraviolet light, and this is the thing that we are all vitally interested in fundamentally. How much change is there in the amount of ultraviolet light?

Now, it's my understanding that some of these models will look at this entire column, and I believe that there are some models that show that there is a decline in the stratospheric ozone—and that was a quote I heard from the Senator; he mentioned specifically the stratospheric ozone—yet the same models say that the total amount of ozone in the column is unchanged.

I believe that in some instances you will see references to a reduction in stratospheric ozone, and the main thing you want to concern yourself with is the total amount of ozone in the column. Here, repeating my earlier statement, if there are any of these models now extant that show that under present levels of emissions there is more than a very nominal reduction of the ozone expected within the next two decades, I would like very much to see them and we would be glad to respond for the record.

We are just basing the information on what we know and what we have been told and what we see, and if there is something else here that we are not aware of, we would be glad to respond for the record.

Thank you.

Mr. **Shimberg**. Thank you.

Mr. Turner?

Mr. **Turner**. Yes. Senator Chafee raised the issue of reputable scientists. There is a portion of the scientific community out there that is not as definite in their opinion of cause and effect as the ones you heard yesterday. However, I do believe that the agreement to a cap is a response to the unknowns of the issue, and therefore Senator Stafford's question about why we haven't responded, I think the producers are responding.

Mr. **Mandell**. We also agree that given the accuracy and the uncertainties of the data to date, a freeze on present production is an appropriate action, coupled with serious, possibly expanded, continued testing.

Mr. **Shimberg**. Thank you. The second part of Senator Stafford's question is a request for information to be supplied for the record. The question is, "Please provide the committee with a list of every scientist known to the Alliance who has stated in a peer-reviewed presentation that either there is no ozone depletion or that CFC's are not responsible."

Mr. **Traflet**. Well, I think we will all have to respond in writing to that.[1]

Mr. **Shimberg**. That would be fine.

Mr. **Shimberg**. I will resist the temptation to ask a series of questions of my own.

We will stand in recess until the members come back. Thank you.

[Recess.]

Senator **Baucus**. I again apologize to the witnesses and thank them for putting up with this inconvenience and disruption.

The question I have goes to how are we going to get a global international agreement? You want one. I think we all want one. We don't want to go it alone; we want an agreement.

My question goes to, if we have a cap, say, on emissions, say all countries agree, what additional burden does that place on developing countries or Third World countries? A lot of those countries are in climates where the temperature is a little warm, and theoretically, as they develop, they move to air conditioning, refrigeration, even more than they now have.

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[1] Note.—Allied-Signal agrees with the DuPont response of May 28 on this question. (The DuPont response may be found at p. 375.)

How easily will those countries be able to develop if there is a cap on CFC emissions, CFC 11 and 12, which are basically used in refrigeration and air conditioning? I am just trying to put myself in the shoes of some of these other countries. It seems to me if I were in their shoes, I would see these caps and I would think to myself, "This just isn't fair. You know, all these other countries have air conditioning. The United States has it, particularly. Now we're growing and we're developing, and we can't use CFC's. They can maintain their present usage, but we can't. So, what the heck," I am speaking now as one of these hypothetical countries, "why should I go along with this global cap? You know, it hurts me more than it hurts them."

I wonder if any of you could address that, the concern that a Third World country might have if there were a cap at current rates or current production?

Mr. FARBER. I will respond again from an outsider's position on the CFC manufacturing position. I think if you see a cap imposed on——

Senator BAUCUS. I'm sorry?

Mr. FARBER. If you see a cap imposed on all manufacturers, and there is a developing market for those materials in these developing countries—you have put your finger on one of the main incentives for developing alternatives—that is a market that the U.S. producers and the global producers will want to capture and go after. So you will see alternatives come along quicker and you will probably see some conservation measures within the industry users taking place anyway with the cap which will free up some of the global production already available for these developing markets until the alternative materials become available.

Senator BAUCUS. But that doesn't address the question because the question is that a cap puts a greater burden on them than it does on us. It is a disproportionate because we could still use our 11 or 12, whichever one it is, in our automobiles or our refrigerators and so forth, which is cheaper. But these other countries, when they are developing and want to buy refrigerators or put air conditioning in their autos or what-not, have to pay more. So that is not fair. Sure, you could come back and say, "Well, the market will develop and so forth," and that probably is the case. The market will develop. But still, there is a great cost, a greater burden on those other countries than there is on the United States. So the argument therefore runs that that country is less inclined to go along with this.

Mr. JEANSONNE. Senator, one other view on this would be the following. I certainly agree that home refrigeration would be one of the first items that a developing country would want to bring to their citizens, and in this instance, CFC 22, which is eminently suitable for home refrigeration or that sort of thing, would be an answer and it could be part of the solution. In other words, over the years, if we were to encourage the use of CFC 22 as the refrigerant of choice in home refrigerators, it would greatly alleviate or simplify that particular problem, which I happen to believe would be one of the more serious considerations.

Senator **Baucus**. I guess what I am getting at is that to the degree that conversion to substitutes creates a problem on the United States because of the additional costs, that that same burden is placed on other countries where there is a cap to have to live with that greater burden, or the conversion to substitutes is not that much of a cost, which means that it is not that much of a burden on developing countries.

Mr. **Blanchard**. I think there may be an interim period where one would not have to restrict the activities of the developing countries. They represent less than ten percent of the world's production today. Their growth rates are not that high. While the developed world moves to alternatives as a result of a production cap, even if their use increases significantly in a percentage, you certainly haven't added much to the burden of the chlorofluorocarbon issue. Perhaps at that point then one can see your way clear to moving toward the alternates.

But I would agree with you there is no question it is an issue. The developing countries can least afford the more expensive material. And therefore, I think there is going to be great pressure to provide them some means of bridging, and it could be a bridging type period, and based on the relatively low production and consumption levels today, that may be acceptable within a worldwide framework of managing the chlorofluorocarbons in those countries.

Mr. **Traflet**. Senator, the other thing is that the Europeans, either by legislation or by voluntary compliance, will be reducing their aerosol production or the use in aerosols. What would happen if they knocked the aerosols down to our level? They would have over fifty percent of their capacity available for export, and that should take care of the needs of the less-developed countries for the period until new materials are developed.

Senator **Baucus**. Anyone else?

Mr. **Mandell**. I think there would be many changes, Senator, in the whole world economic system if there were caps on production. There would be a powerful incentive. There would be a need to develop alternate materials almost immediately to absorb world growth in demand, and some of those products may conceivably come in at relatively competitive prices. There would be increased incentive to use alternatives in all parts of the world, in developed countries as well as the less-developed countries. There would be a shift in the balance of value of goods and distribution of goods. But I think it could be met in a relatively open-enterprise system and with the scientists doing their best to come up with economic substitutes.

Senator **Baucus**. Do all of you think the United States should strive to be, within relative limits, the world leader, or should we pass the baton of leadership to other countries; Japan, for example?

Mr. **Traflet**. I think we should really do this jointly with other countries of the world.

Senator **Baucus**. I asked about leadership. Where there is a vacuum to be filled, if there is a need for leadership, some place——

Mr. **Traflet**. I think we already are leading.

Senator **Baucus** [continuing]. Somebody else is going to fill that vacuum.

Mr. **Traflet**. We are leading very well, I think. In fact, we are concerned that we are providing too much leadership. We would like to see a more balanced view of what is happening in the world. But let me just say one other thing in relationship to that.

Senator **Chafee**. That will be a classic quote, Mr. Traflet.

Maybe you would want to revise the record when you get it. I am not so sure you want it to go forth from these chambers, "We are too much of a leader."

Mr. **Traflet**. No, but actually what I think is that the world is perceiving that the success of this UNEP is a very good thing. In fact, I have read some comments that this is one of the first times that so many nations of the world have gotten together and gotten close to an agreement. We have a lot of other problems in this world, not just on the environment, but if you stick with the environment, on acid rain, and we have problems with earth-warming and the production of too much carbon dioxide and so forth.

Senator **Baucus**. Have we provided leadership on aerosol cans that worked?

Mr. **Traflet**. We did it ourselves, but the rest of the world didn't follow. So it would be much better if we could have gotten that agreement.

Senator **Baucus**. Excuse me. You yourself said that they're coming along.

Mr. **Traflet**. All right.

Senator **Baucus**. I mean, Scandinavia has banned, I think; Canada has. I think Switzerland and Austria have. There is a list of countries that are now beginning to move in the same direction as the United States, as I understand it.

Mr. **Traflet**. But our leadership was how many years ago? And what happened in those intervening years? Nothing. If we had agreed together at that period of time, maybe we would have had those aerosols reduced in Europe long before this.

Senator **Baucus**. There are a lot of "maybe's" in life. The fact is we did do it, and so did they a little later.

Mr. **Blanchard**. I don't think we can provide too much leadership. So I would say that we should be the leaders. I think we are being the leaders. I think Du Pont——

Senator **Baucus**. Du Pont is.

Mr. **Blanchard**. No, but I am talking we America and we American industry, we American environmental groups, and that I think that the work that is going on in the United Nations Environmental Program, which Mr. Traflet has referred to, which we think is demonstrating for the first time the ability of the world to work together on an issue is a result of the leadership that we are supplying as an industry and as a group of producers and users.

And, in particular, in calling for a limitation on growth last fall, which was received very unpopularly around this world by other producers, that is leadership: taking a position that is unpopular but pursuing it to an international accord.

Senator **Baucus**. Senator Chafee, questions?

Senator **Chafee**. No, thank you, Mr. Chairman.

Thank you, members of the panel.

Senator BAUCUS. We all thank you very much. You have worked hard for this, and we thank you for your appearances here. Thank you very much.

Our final panel will be: Mr. Richard Barnett, of the Alliance for Responsible CFC Policy; Mr. David Doniger, Natural Resources Defense Council; and Mr. Irving Mintzer, World Resources Institute.

Mr. Barnett, why don't you proceed?

STATEMENT OF RICHARD BARNETT, ALLIANCE FOR RESPONSIBLE CFC POLICY

Mr. BARNETT. Good morning, Mr. Baucus, Mr. Chairman. We appreciate the opportunity to be here to testify to you this morning. I am Richard Barnett. I am chairman of the Alliance for Responsible CFC Policy. I am also vice president of York International Corporation and general manager.

On behalf of the members of the Alliance, I would like to thank you for the opportunity to appear before you and the subcommittee today. The Alliance continues to believe that our policy is sensible from the perspective of both environmental protection and the economic impact on the U.S. economy. The Alliance has recently stated that it will accept an emission freeze at or near current levels for fully halogenated compounds so long as the international agreement provides for periodic scientific, economic, and technology review. The policy outlined, we believe, will most efficiently bring about the development of substitute compounds.

Let me summarize the key points from our written testimony.

First, with regard to the status of the international negotiations, the Alliance feels that the international agreement is the only means of developing an environmentally effective program without placing U.S. industry at a competitive disadvantage. The Government's effort in this area should be to reach an effective international agreement that minimizes the cost to our economy, but also promotes the development of substitute compounds. Attached to this testimony is an outline of what factors we consider to be important in this negotiating process.

Second, we continue to stress that an effective international agreement that freezes emissions of fully halogenated compounds, accompanied by periodic scientific and economic and technology review is an adequate policy to protect the environment and to spur development of substitute compounds. Our analysis indicates that a weighted production of CFC 11, 12, and 113 at 1986 levels would cost the economy approximately $1 billion during the period 1988 through the year 2000, primarily due to increase in CFC prices. Annual costs would increase $180 million in the mid-1990's. CFC prices are estimated to be three or four times higher than current levels by the mid-1990's, but would be expected to moderate in the late 1990's as new substitutes become more available.

These price increases are likely to have a desirable environmental effect in the short term by encouraging user industries to implement cost-effective emission-reduction programs where possible. Also, the freeze is expected to curtail 1.1 million metric tons of projected CFC use by the year 2000, or the equivalent of four years' production at current U.S. production levels.

This substantial unmet market will provide a significant stimulus for the development of substitute CFC's or other alternative compounds. It should also be noted that a freeze at 1986 levels will actually be a reduction step if current growth patterns are followed and implementation occurs between 1988 and 1990.

With regard to proposals in the Senate bills S. 570 and S. 571 to initiate a 95 percent production rollback, it is impossible to place cost estimates on the impact of such a dramatic measure. Currently, 28 percent of CFC production is used to service installed equipment. Capital stocks would become prematurely obsolete for many consumers and CFC user firms.

As an example, fully halogenated compounds are currently used to operate 100 million home refrigerators and 91 million automobile air conditioners. The 95 percent rollback would render approximately 18 million auto air conditioners and a million of the home refrigerators useless in 1993 if CFCs were not obtainable.

Such a Draconian measure as that contemplated by the Senate bills could actually bring on these undesirable impacts more quickly than the schedule contemplates if CFC producers lose economies of scale to operate their facilities and decide to exist the business entirely.

The massive consumer dissatisfaction with the effects of such a program and economic cost to society could threaten the viability of our ozone protection efforts.

Third, efforts internationally or domestically to negotiate or promote short-term reduction steps are ill-advised. Reduction measures, particularly in the United States, where we have unilaterally eliminated aerosol uses, that occur prior to the commercial availability of acceptable substitute compounds, would lead user industries to choose currently available but less desirable alternatives that are either more toxic, carcinogenic, flammable, or less energy-efficient than the current CFC compounds.

Senator BAUCUS. Could you please summarize?

Mr. BARNETT. Yes. I am doing it right now.

Senator BAUCUS. Thank you.

Mr. BARNETT. In our view, the unilateral CFC program in the United States that attempts to govern the world economy through trade sanctions will only serve to further isolate U.S. industries in the world market. Such an effort should be discouraged.

The focus of the U.S. Government efforts should be to achieve a simple, fair, and enforceable unilateral agreement with broad participation among the world community. The U.S. ozone protection program should be consistent with and no more stringent than the international agreement. It is in this manner that U.S. technology know-how will provide for protection of our environment and ensure that we remain competitive in world markets.

Thank you very much for the opportunity.

Senator BAUCUS. Thank you, Mr. Barnett.

Mr. Doniger?

STATEMENT OF DAVID DONIGER, NATURAL RESOURCES DEFENSE COUNCIL, WASHINGTON, DC

Mr. DONIGER. Thank you, Senator Baucus. I am speaking today for the Natural Resources Defense Council and also for the two dozen members of the National Clean Air Coalition. We support the phaseout policy articulated by EPA last fall, and twice cleared as official Government policy, and we also commend you and Senator Chafee and your cosponsors for the introduction of S. 570 and S. 571.

I would like to focus on four main points: What is the measure of success in either the international agreement or the domestic situation? Second, how close is the international process to any deal or to a deal that meets that measure of success? Third, I would like to examine who is trying to sabotage the U.S. policy within our own Administration? Fourth, I would like to talk a bit about what should happen in the domestic rule.

First, I think the testimony yesterday, as well as previous scientific analyses, can lead to only one conclusion; that is, that the measure of success is at the very least stabilizing the atmosphere for chlorine and, hopefully, cleansing it.

The atmosphere is greatly out of balance for CFCs and halons. An 85 percent reduction or more is needed just to stabilize and eventually to clean these compounds out of the atmosphere. Any lesser reductions would let the stockpile of these longlived chemicals continue to build up—an atmospheric stockpile that is apparently already high enough to cause the Antarctic hole and other disturbances in the ozone layer.

We should remember that the 95 percent phaseout policy was developed without taking the Antarctic hole into account. Yesterday, scientists who investigated the hole directly have testified that it is probably linked to CFCs, and one testified that he believed he had found "the smoking gun."

So any agreement that reaches less than an 85 percent reduction to stabilize the atmosphere and a 95 percent reduction to actually clean out the atmosphere is one that does not meet the measure of success.

How close is the international process to reaching such an agreement? Well, the recent press reports, I think, created a misleading and exaggerated impression that we are close to any agreement and close to a good one as well. I think we in fact are not that close.

The Chairman's document from Geneva, which is attached to my testimony, contains a number of mutually exclusive alternatives, the most lenient of which is a twenty percent reduction that would be an environmental disaster. It would also not be enough to promote substitute chemicals.

Even the most stringent option would tentatively assure only a 50 percent reduction in only CFCs, not the halons, by the mid-1990's, and that is less than 50 percent if any allowance is made for growth in developing countries. That is far less than the global 85 percent reduction needed just to stabilize things.

Now, how did that come to be? With the hard bargaining remaining ahead of us, the Chairman's text would not be such a problem if the United States is very clearly committed to its policy of phaseout. But there is a problem in the United States government. The month of April, as you know, saw an attempt to sabotage the established U.S. policy by junior and middle-level officials in the OMB, in the White House Office of Policy Development, in the Department of the Interior, the Commerce Department, and several other agencies.

Throughout the month of April, a group of as many as thirty people met repeatedly on every detail of the CFC issue. They hostilely grilled EPA. They started and finished their series of meetings with meetings with industry officials. We had one opportunity to meet with them rather late in the process. One OMB official described skin cancer as something which should be regarded as a voluntary consequence of sun exposure which might be ignored by Government. I have attached the thoughtful reply of Dr. Margaret Kripke, the Chair of EPA's Science Advisory Board subcommittee.

In the end, these agencies did not succeed in making an official change in the U.S. policy, but two of their minions were on the delegation to Geneva, and they did create serious problems over there. It was difficult for our negotiators even to go so far as to propose the "hard" version of the 50 percent reduction—the one going into effect unless called off by two-thirds of the countries—and there was little heard from our government about phasing down all the way down to 95 percent.

Now, if we are going to have an effective agreement, it has got to include the halons, it has got to provide that we get to 95 percent, especially in light of what was said yesterday about the Antarctic ozone hole, and it has got to have the effective measures to control trade, such as you propose in your bills.

On these points, the EPA Administrator must not allow any compromise. I hope you will demand commitments from him tomorrow about what the U.S. policy is in terms of what is an acceptable international agreement.

On the domestic side, NRDC has agreed with EPA to extend the deadline for the domestic rulemaking to December to get out a proposal, and we signed papers on that on Monday. They are included with my testimony for your information.

We think, as we have said in previous testimony, that there should be a domestic rule that includes a phaseout. It should also include strong trade restrictions such as are in your proposed legislation. That is the way to goose the international negotiations along to a good outcome, and it is the way to have a safeguard for the failure of the international process.

I hope that when questioning Mr. Thomas tomorrow, you will ask for a clear explanation of what the U.S. policy is. I believe there is an effort going on within the administration right now to restrict what he can say tomorrow, and you should ask him about that, too.

I think that EPA has the necessary authority to act domestically, but there is a question with this administration, as always, of whether it has the will and the good sense to do so. So we recommend that your subcommittees move forward with the legislation as rapidly as possible. There should be a legislative safeguard, and we look forward to working with you on the enactment of S. 570

and S. 571, or some combination of those bills, which we strongly support.

Senator BAUCUS. Thank you, Mr. Doniger.

Mr. Mintzer?

STATEMENT OF IRVING MINTZER, WORLD RESOURCES INSTITUTE, WASHINGTON, DC

Mr. MINTZER. Thank you, Mr. Chairman. My name is Irving Mintzer. I direct the energy and climate program at the World Resources Institute, an independent policy research center here in Washington.

Last week I returned from the Geneva negotiating meetings, participating in the international process to develop a protocol. I am a member of EPA's scientific advisory panel on the ozone risk assessment and would like to talk to you today about three principal topics: first, the ongoing efforts to reach an international protocol to limit CFC emissions; second, the current status of efforts to develop safer alternative formulations of CFC's and non-CFC substitutes to replace the traditional CFC compounds; and some of the trade implications of CFC regulatory policy.

Let me begin by discussing the status of efforts to achieve an international agreement. WRI enthusiastically endorses the process of attempting to negotiate an international settlement. We view the Vienna Convention for the Protection of the Ozone Layer as a historic accomplishment in the evolution of international environmental cooperation. Under the able leadership of Dr. Mostafa Tolba, executive director of UNEP, the last week of negotiations in Geneva was, although difficult and protracted, able to bear considerable fruit. Its achievement was the production of a draft protocol that is positive and constructive. This conference draft document could form the basis for a powerful agreement and set a lasting precedent for future international cooperative efforts.

It is important to note, however, that the conference draft submitted for your review is not legally binding until approved in the capitals of the signatory states. For this reason, the next phase of the negotiations, which will occur over the next 5 months in dozens of capitals, is of crucial significance.

We of the international community of nongovernmental organizations look to the members of this committee and to others in the Senate to fight vigorously to sustain the important aspects of this compromise and to push future agreements beyond the level of a commitment to a 50 percent reduction. Your role is absolutely critical to achieving our shared goals of protecting the environment, sustaining economic growth, and in particular, reducing the risks of ozone depletion.

Needless to say, the current conference draft is not a perfect solution to the problem of global ozone depletion. It does not completely eliminate the risk of future CFC buildup. It is a compromise proposal which covers only the most dangerous chemicals, reduces their production and use by 50 percent, and provides for periodic reviews of the science to determine the adequacy of the control strategy.

The World Resources Institute strongly endorses what is referred to as Option B in this document, that calling for automatic reductions of 30 percent beyond the initial 20 percent unless two-thirds of the parties vote against it. Such a negative-trigger approach is much less likely to overturn the proposed reduction schedules in future years.

To achieve the draft proposed compromise, each of the parties to this negotiation made significant concessions in the last year. In the interest of reaching an international agreement, the United States has agreed in this draft to delete the halons and the chlorinated solvents from the conference draft and to remove explicit mention of the 95 percent target for future reduction. These compromises would not significantly weaken the agreement, because the halons and the solvents together contribute little to the current risk of ozone depletion. If their recent high growth rates continue, they can be included in the protocol at a later date.

Dropping the explicit target of 95 percent reductions would not be a problem if the commitment to 50 percent reductions and the existing position in the draft agreement for further possible reductions are observed faithfully. Risks will rise rapidly, however, if those who argue to limit the reductions to levels that reduce emissions by less than 50 percent or propose less than vigilant attention to the emerging scientific detail and the need for further reductions beyond 50 percent are allowed to undermine the current situation.

On the basis of my observation of the Geneva meetings, I am optimistic about the prospects for reaching an international agreement this year. It is important to note that the European Council of Ministers has not approved this draft to date. They are scheduled to consider the issue at a special meeting on May 28. Those struggling to gain approval of the compromise, recognizing the need for further reductions, have many difficult hurdles to surmount. Resistance by some of the chemical companies in Europe is stiff. Only with strong and continuing U.S. support and, in particular, with the vigilant efforts of this committee will the more reasonable European Governments be able to overcome this strong resistance.

I am not, however, convinced that the draft agreement reached in Geneva will be adequate by itself to protect the ozone layer. It appears likely that the agreement will not cover all ozone-modifying chemicals, ignoring the halons, which are the fastest-growing compounds in this group. An agreement of the sort proposed will help and is substantially better than where we are now, but is not by itself enough to solve the problem. Significantly reducing the risks of ozone depletion will require the phaseout of the most harmful compounds and the rapid introduction of alternative, safer CFC formulations.

The controls envisioned in the current draft proposal may not be adequate to stimulate the rapid introduction of these substitutes. To provide adequate economic incentives for the rapid introduction of alternative, safer CFC's, the United States and other nations must be prepared to enact strong CFC control regulations, if necessary to act unilaterally.

Turning for a minute to the question of safe CFC substitutes——

Senator BAUCUS. Can you please summarize, Mr. Mintzer?

Mr. MINTZER. Yes. Du Pont, Penwalt, Halocarbon Corporation, and others have recently indicated that they can now or will soon be able to produce safer, alternative CFC's in commercial quantities. Matching the best of these to the myriad of present CFC applications will take time as well as further study.

WRI, for one, remains confident that with appropriate regulatory signals and market incentives, American ingenuity and technical skill can quickly bring these products successfully to market. We have been completely persuaded by Du Pont that under appropriate conditions the new, safer CFC's can be produced in commercial quantities in less than 5 years.

To conclude, I would just summarize by saying that the industrialized world has not only the responsibility to protect the Earth's ozone layer from manmade chemicals but also the capability to do it without economic and social disruption. CFC emissions can be cut by at least 50 percent within 5 years by actions that will perpetuate both a healthy global economy and a healthy ozone layer.

To provide adequate economic incentives for the rapid introduction of these substitutes, the United States and other nations must be prepared to enact strong control regulations. Because American companies are capable of producing safe CFC's, they could lead the world with the next generation of chemicals. If we fail to meet the challenge of development in the United States, we will surely be buying these chemicals from other countries in the future.

Senator BAUCUS. I thank you. I am going to have to leave for this vote. I think Senator Chafee is going to return, and as soon as he does, we can reconvene the hearing. If he does not return, I will return in about 6 or 7 minutes. Thank you.

[Recess.]

Senator CHAFEE. All right, ladies and gentlemen, let us resume.

Mr. Barnett, as I understand your testimony, you are saying let us not have cuts now. Is that what you are saying?

Mr. BARNETT. We are saying that we believe that worldwide negotiation is essential to solving a worldwide problem, and we believe that a cap on existing—at or about existing production levels is one that is saleable to the international community and it is one that seems to provide sufficient time for further review of the information in the scientific and economic assessment.

Senator CHAFEE. In other words, you would have a freeze, and you want an international agreement. But as you know, in the international agreement proposed, at least one of the options says a 20 percent cut in 4 years from now. What would you say to that?

Mr. BARNETT. We think that the proposal for the 20 percent cut in 4 years is probably premature. It is something that is very easy for the Europeans to do by simply banning aerosols where there are viable substitute materials to do that job. But it would place the U.S. industry in a rather difficult position, since there aren't available substitute materials that we could readily go to for many of our applications.

Senator CHAFEE. Therefore, you are of the view that there is not too big a problem out there to worry about; is that correct?

Mr. BARNETT. I think that you are misrepresenting what the Alliance is saying. The Alliance has recognized the potential for a problem and is trying to also match that potential problem with the proper solutions so that we don't have the risk of introducing bigger problems than what we potentially could be solving.

Senator **Chafee**. What might those bigger problems be?

Mr. **Barnett**. Worker and consumer safety. Also, we are not sure that these new chemicals are, in fact, environmentally benign, and we are not sure that they are also not carcinogenic. These tests have yet to be performed, and we do not know the toxicity of these proposed new chemicals.

Senator **Chafee**. But if we have a problem with the ozone layer and the deterioration of it, don't we have to do something even though there might not be substitutes? I mean, if the alternative is destroying the ozone layer or delaying until we come up with absolutely safe, economic substitutes, maybe the decision ought to be, "Well, we will just go ahead and ban the CFC's or reduce them back, and maybe everybody won't be able to race around with an air conditioner in their car." Is that the end of the world?

Mr. **Barnett**. Well, I think that, unlike Senator Stafford's projection that the Alliance's position was status quo, the Alliance is actually recommending a very aggressive position with regard to action today of capping production at 1986's level. I think you have accurately depicted in several of your questions that there has got to be some middle ground between two extremes, the one extreme of do nothing, and the second extreme of complete phaseout of CFC's that matches the risk with a proper response.

The Alliance is professing that that proper match of risk with response is a short-term cap at existing levels with a continual evaluation of the science and the economic problems and the available substitutes with potentially further action either to relax the cap or to make the cap more severe in a subsequent period of time. We are recommending a 3-year review process.

Senator **Chafee**. Do you think we are going to find much more scientific evidence that the ozone layer is being depleted?

Mr. **Barnett**. I really can't answer that, but I do know that we can find out one heck of a lot more about the potential substitutes—their toxicity, their potential impact on the environment, and also their potential impact on energy use and worker and consumer safety. That is the answers which we and industry need to know. As a user of these chemicals, I can't buy them today to find out what they are, even though I have recommended to several of our design groups not to design another product using the existing chemical compounds.

Mr. **Doniger**. Senator.

Senator **Chafee**. Yes?

Mr. **Doniger**. One important assertion that the Alliance is making is that merely freezing the allowable emissions would be enough to move the substitutes forward at the speed we need to go.

Senator **Chafee**. Well, that was going to be my next question. You go ahead.

Mr. **Doniger**. We disagree with that. I think that the three independent sources that have looked at this question—EPA, the World Resources Institute, and the Environmental Defense Fund—and all three produced answers which independently are in the same ballpark, that a freeze doesn't get the speedy work on substitutes. You won't produce the price changes that the producers insist are necessary to create the market for substitutes in any short term unless the allowable production is phased down by at least 50 percent in 4 or 5 years.

Senator **Chafee**. What do you say to that, Mr. Barnett?

Mr. **Barnett**. I think that there are examples by the difficulties of shortages of oil in the world that might impact on this. But I think that we ought to focus on the real issue, and that is, what are the substitutes and what are the availability of those substitutes and what is the demand for those substitutes? Only part of the creation of a demand will be economics. Certainly, that will be an important part. But there are other things with regard to the demand for substitutes, and that is the user's desire, fervent, earnest desire to find other chemicals which can be used in our products.

Let me give you an example. If you can picture in your mind a matrix whereby you have the costs of the product—the CFC in your product going from high to low, and on the other axis the cost of capital, the capital intensity of changing your product to use a different CFC, going from high to low. Where you have a product that has a relatively low cost to change and a relatively low product cost, if CFC is relatively insignificant and you can make two or three changes from 11 to 22 to something else as it comes along. But where you have a product, as with automobile air conditioning, household refrigerators, central air conditioning equipment, that require significant capital expenditure in order to redesign the product, you want to be sure that you do it right the first time. We need the substitutes identified. We need the engineering data identified to us so that we can start applying new products.

It really, quite frankly, in the case of a household refrigerator, an automobile air conditioner, a central air conditioner or anything else, and many food freezing processes, the cost of the CFC is relatively insignificant. It's the capital cost to convert. We've got to do it right the first time. You've got to give us time to identify these substitutes.

Senator **Chafee**. Yes, but Mr. Barnett, the problem is what can we use to be a technologically forcing agent?

Mr. **Barnett**. Just cap production.

Senator **Chafee**. In the automobile industry, we enacted legislation and said you've just got to reduce your emissions, you've got to increase your mileage. And they objected and said they couldn't do it. And they did it. And they never would have done it absent that. I mean, they will acknowledge that. Everybody will acknowledge that, I think.

Now, here you say you require all these changes in the design of the air conditioners and so forth. But what is going to make you do it? Do you think a cut in 4 years, starting 2 years from now? That is taking the strong case at Geneva. They have a weaker one at Geneva. But taking the strong case, a freeze for 2 years, and then you wouldn't even go into the cut until 2 years after, you wouldn't even have that hanging over your head. Is that correct? You wouldn't agree to that?

Mr. **Barnett**. We would suggest that a cap at 1986's level is a very significant economic incentive for U.S. industry to actively and aggressively seek alternative fluids.

Mr. **Mintzer**. Senator?

Senator **Chafee**. What do you say, Mr. Mintzer?

Mr. **Mintzer**. I would like to comment on the availability of substitutes and the likelihood that we can, with measures such as those being proposed for strong reductions, induce their rapid entry into the market. The discussion that has taken place so far makes it sound as though we must wait for the discovery of some new law of physics before substitutes can become widely available. In fact, much work has gone on. In some cases, work has been halted. But the family of safer, alternative CFC formulations is not beyond the reach of clever chemical engineering and the best efforts of U.S. industry.

Some of these compounds are already available in the market. CFC 22, a hydrogen-containing CFC, is already widely used. Penwalt, in its testimony today, indicated that they are currently prepared to sell a mixture of CFC 142 and 22 that can take the place of some applications of CFC 12.

Recent indications have been made publicly that you can now buy in thousands-of-pounds quantities CFC 134A, which may be a direct substitute for CFC12 in refrigeration applications, without requiring large-scale capital retooling and new capital purchases by consumers.

Clearly, some of these compounds will face several years of additional toxicity testing and engineering development. But unless we give clear and unequivocal regulatory signals to industry, we may wait for those several years to take place until well after even the Geneva agreement suggests that reductions are appropriate. We need you to give clear signals, clear market signals, clear regulatory signals, to Du Pont, to Allied, to all of the producers that we would like to see these substitutes and that the market will welcome these substitutes and pay for these substitutes now.

We at WRI have suggested and recommended a $5-per-pound tax on CFC 11, 12, and 113, so that the substitute products which now look uneconomic at $1 or $1.50 a pound could compete on a more equal footing with the more traditional compounds that have been produced in such large quantities in the past. We need to give these incentives to producers so that they work quickly to bring the substitutes into the market.

Senator **Chafee**. Well, my problem, Mr. Barnett, is that I don't think there is anything out there under these proposed agreements, which haven't even been enacted, to force you folks to really do the things that you say you are going to do if the market works that way. Do you think a cap alone will make you do all these things?

Mr. **Barnett**. Well, I think that you are certainly discounting the fact that you don't believe that people in industry are going to do it out of conscience, so you think we're going to have to have a gun to our head to do something, obviously, from what you have said. I would tend to disagree with that most emphatically.

However, I also think that the cap is going to severely inhibit any growth potential for most of our industries. Most of us are anxious to grow in world markets, and we are anxious to grow our product lines and our offerings. We are anxious to grow our employment rate to keep our people working. If we put a cap on these chemicals, we will not be able to grow. We will have to look for new chemicals to put into new products, but we will still then have the availability of the existing chemicals to put in your air conditioner and in your refrigerator so you won't have to throw it away in case it gets a leak. I think that is an important consideration for the consuming public.

I also believe that this cap will provide a significant economic incentive for U.S. industry to go very aggressively to take a leadership position to develop patents for production and patents for compounds so that we in turn can export that technology worldwide.

Senator CHAFEE. Well, I would hope that would be true.

Thank you, Mr. Chairman.

Senator BAUCUS. Thank you, Senator.

Mr. Barnett, you said—and I know we would like honestly to think it's true—that industry will for the betterment of mankind move in the direction of developing substitutes for that reason rather than for the reason that it has to; that is, because there is some regulatorily imposed mandate. That may or may not be true.

But the fact is the evidence isn't all that significant that industry will on its own, because it wants to improve the health of mankind, develop these substitutes on its own; that is, I think we will all agree that the driving force behind any business concern is its return to its shareholders, to the degree it's a publicly held company. That is the driving goal for most American businesses. And whether or not it should be is another question. The fact is I think we will agree that is the primary duty of a company, to get its best return for its shareholders.

Now, in 1975, 12 years ago, in a report called "Fluorocarbons in the Environment," a report of the Federal Task Force on Inadvertent Modification of the Stratosphere, called IMOS, Council on Environmental Quality. It is dated June 1975.

Let me just read from it, beginning with its fourth paragraph:

> The task force has concluded that fluorocarbons released to the environment are a legitimate cause for concern. It also has concluded that unless new scientific evidence is found to remove the cause for concern, it would seem necessary to restrict the use of fluorocarbons 11 and 12 to replace fluids in existing refrigeration and air conditioning equipment and to closed recycle systems or other uses not involving release to the atmosphere.

That was 12 years ago, and the fact is that I don't see industry on its own, for the betterment of mankind, moving to find those substitutes. We operate by deadlines in life. We like to have our cake and eat it, and we realize that is human nature and we realize it is human nature often not to do something until we have to do it.

It just seems to me that we are all better off in this country the more quickly we move to find those substitutes, and I just hope that the Alliance moves more expeditiously to find those substitutes.

I was a little bit disturbed in your testimony when you go on and on and on about the cost of moving to substitutes. You don't mention one word about the costs of not moving to develop substitutes.

I asked Ms. Claussen, from the EPA, this morning what the costs would be of not moving to substitutes; that is, in terms of cancer and other adverse health effects. It is her professional judgment that the costs of not proceeding far outweigh the costs of proceeding; that is, to the development of substitutes.

So I hope that when the Alliance looks at the cost factor of moving towards substitutes, it also legitimately addresses the costs of not moving to substitutes; that is, the costs that the consumers are going to have to bear.

Mr. **Barnett**. We obviously believe that that must be the proper balance, or we wouldn't be advocating that substitutes be developed.

Senator **Baucus**. Mr. Doniger, what about the industry's position that we should not move unilaterally in international negotiations, that it is going to hurt the U.S. competitive position if we have a fairly strict law that forces the industry to move to develop substitutes, it is going to cost U.S. industry, a cost that our competitors will not have to bear, and it just does not make sense for us to go it alone? What about that? That sounds like a pretty good argument to me.

Mr. **Doniger**. Well, I believe that the U.S. has, as Senator Chafee has been saying and as you have said before, a great deal of leverage to play as a trading partner. Perhaps the silver lining in having so large a trade deficit is that you get some control, if you are willing to use it, over other countries' behavior on something this important. If you are willing to use that to leverage in trade restrictions that condition the continued access to our markets on other countries' making the same kind of phased change in CFC policy that we would be asking our industries to make here.

It seems to me that persons who counsel against doing that, whether they are intending to or not, are recommending that the United States give away an important card that we have in the international negotiations, because we know—I know from my personal involvement as an observer in the first two meetings and from many reports that we have gotten back—that the possibility of U.S. trade restrictions has really caught the attention of Japan and of the European Community. And if one says we will not have a domestic program and we will not use that leverage, then one, I think, is playing into the hands of the British and the French and the Japanese, the ones who want to have a minimal agreement.

So, I believe, first we need to use the domestic program with reductions and with trade restrictions to goose the negotiations constructively along, and we need to have a safeguard through such a program in case the agreement produces only a freeze, only 20 percent, or even only a 50 percent reduction.

Senator **Baucus**. What about the point of one of the earlier witnesses that if the United States goes alone and, say, we imposed some kind of restriction on foreign countries' CFC's or their products that use CFC's in this country, that, sure, we use the leverage of our market in preventing those nonconforming products from coming into the United States but we hurt ourselves because we can't export to other countries?

Mr. **Doniger**. The U.S. and like-minded countries constitute so significant a market for these other countries' goods that we can condition continued access to that market on those other countries' reforming the use of the CFCs for all purposes—their own domestic purposes and their own export purposes. That way we will be able to keep everybody on a level playing field. As you were saying with respect to the dumping problem with the semiconductors, the whole point of U.S. trade restrictions is to stop the Japanese from continuing a practice which is going on not in the U.S. but in third countries. I think that it will turn out that such restrictions work. It is a good example of how we can use the leverage on this important issue.

Senator BAUCUS. So your analogy is this: that as in the case of the Japanese semiconductor industry, because they are dumping in third markets, we impose a tariff on Japanese semiconductors in support of the United States as a way to get them to back off from dumping in third country markets. So your analogy would be that in this case, in order to get, hypothetically, the EC to move in the same direction we might, that if we put a limitation on their products imported into the United States, that that will put leverage on them to prevent them from dumping their nonconforming CFC's into third-country markets?

Mr. DONIGER. I am sure that Luxembourg or Switzerland or Austria or some little country, relatively speaking, couldn't do that because it doesn't have enough of a market. The market isn't large enough to provide that kind of leverage. But with Canada and the Scandinavian countries and other countries with whom this should be explored, the U.S. constitutes a very large fraction of the export market. And for the Japanese to say they want to thumb their nose at that market in order to pursue a Third World export market strikes me as not a reasonable prediction of how they would behave.

Mr. MINTZER. Senator, could I respond to this issue as well?

Senator BAUCUS. Sure. In about 2 minutes there is another vote. I am sorry.

Mr. MINTZER. I think it's easy to overestimate the export effect of some of these control efforts. In many cases, the value added, the increase in cost to U.S. products that would result from significantly increasing the price of CFC's, would not adversely affect their competitive position. If, for example, the CFC's in the refrigeration loop of a refrigerator increased by a factor of ten in their total cost, and the cost of a $500 refrigerator we were trying to export to the Philippines went up as a result by $20, it's not immediately clear to me that that would vastly affect the overall attractiveness of a $500 or a $600 device.

Similarly, it is not clear that in the many applications where emerging technologies for use of aqueous cleaning solutions in electronics could replace CFC 113, that the result would significantly affect the cost of the resulting devices. It is unlikely that it would affect the cost in a significant way, the cost of a car that uses electronic semiconductor chips to control its ignition.

Senator BAUCUS. What about that, Mr. Barnett? What products are least competitive if we have to move to substitutes? Mr. Mintzer mentioned the additional substitute for a CFC cost in a refrigerator is a relatively low percentage of the total cost of the refrigerator. What products, you know, end-use products, are most sensitive to the costs of substitution of CFC's to some other product?

Mr. BARNETT. Flexible and rigid foams would be the products.

Senator BAUCUS. Pardon?

Mr. BARNETT. Flexible and rigid foams would be the products which would have the biggest impact with regard to that.

Senator BAUCUS. Flexible and rigid foams?

Mr. BARNETT. Foams.

Senator BAUCUS. What about refrigerators and air conditioning?

Mr. BARNETT. Relatively small impact in terms of the product cost and the installed cost is impacted with the CFC cost.

Senator BAUCUS. What percent increase would foam products be on average?

Mr. BARNETT. There are some foam products where the CFC's are as much as 40 percent of the product cost.

Senator BAUCUS. So was that an average figure, 40 percent?

Mr. BARNETT. I don't think I can suggest an average figure. I have heard that it can be as much as 40 percent on some foam products.

Mr. MINTZER. Many of the foam products are not major exports for the United States.

Mr. BARNETT. We don't have a large market in the export of foam cups.

Mr. MINTZER. In many cases they are devices that it is not especially economic to ship long distances, and that's why they're made in a wide variety of places.

Senator BAUCUS. Well, this has all been very interesting.

I want to thank you very much. Our time is up, and the hearing will now adjourn. Thank you.

[Whereupon, at 1:09 p.m., the subcommittee was recessed to reconvene Thursday, May 14, 1987.]

[Statements and other material supplied for the record follow:]

STATEMENT
OF
EILEEN CLAUSSEN
DIRECTOR, OFFICE OF PROGRAM DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
BEFORE THE
SUBCOMMITTEE ON ENVIRONMENTAL PROTECTION
AND THE
SUBCOMMITTEE ON HAZARDOUS WASTE AND TOXIC SUBSTANCES
OF THE
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
U.S. SENATE

MAY 13, 1987

Good morning. I am pleased to have the opportunity to present to you our preliminary analysis of the costs and benefits of possible measures to protect stratospheric ozone, and our view on short-term adjustments that can be made to respond to these measures.

Before describing our analytic process, I first want to underscore that this is an on-going effort, and that we expect to add to and improve our regulatory and economic analysis. We have brought together a substantial data base on costs and benefits, and have used this data base to develop our initial estimates. The numbers presented today should be viewed with some caution as they may be modified in the future.

The discussion of our analysis of costs and benefits will be followed by a brief description of our efforts related to chemical substitutes.

Development of Analytic Framework

The framework that we have developed includes data on the most damaging ozone depleters (e.g. the fully halogenated chlorofluorocarbons, CFCs). This includes CFC-11, CFC-12, and CFC-113; and two brominated compounds: Halon 1211 and Halon 1301. These compounds are used in a wide variety of products and processes.

To accurately characterize the disparate uses of CFCs and Halons, we have collected data and explored control opportunities for 7 broad use categories:

- Solvents
- Refrigeration
- Foam blowing
- Fire extinguishing agents
- Sterilants
- Aerosol propellants
- Miscellaneous uses

For each of these categories, we have looked at different use patterns and technical options for change. As a result, we have broken down the broad uses into 81 specific application categories. For example, within the broad use category of foam blowing, we consider 9 specific applications:

- Extruded polystyrene boardstock
- Extruded polystyrene sheet
  - egg cartons
  - single service
  - single service hinged containers
  - stock food trays
- Flexible urethane foam
  - molded
  - slabstock
- Rigid polyurethane foam
  - boardstock, furniture
  - boardstock, construction & building

We have utilized the technical expertise of a team of consultants to help us explore current uses and control options for each application. The consultants estimated the current CFC and Halon use, identified the technically feasible control options and provided preliminary estimates of control costs. They examined opportunites for emissions and process controls, recycling, and product and chemical substitutes. The firms drew on a range of past work and industry estimates.

The data collected in this initial effort were collated and integrated into a master data base. The cost estimates that were developed for over 600 control opportunites are currently being more fully documented, and will be available for review within one month.

Because of the long-term nature of this issue, control options were evaluated for short, medium, and long term periods. For example, the control options for CFC-11 applications in slabstock polyurethane foams were identified as:

- Short term options (up to 3 years)
  - cotton batting
  - minimum foam density specification
  - minimum foam density specification with alternative blowing agent
  - alternative blowing agents
  - vertical foam chamber
  - water-blown systems

- Medium term options (3 to 7 years)
  - carbon adsorption / recycling
  - formic acid "AB" process
  - vertical foam chamber and carbon adsorption

- Long term options (7 years or longer)
  - CFC 123
  - CFC 141b
  - plastics / semi-flexible foam

The costs, effectiveness, and applicability of each control option were evaluated. The costs of the control options were traced through all steps in their design, implementation, and operation. When appropriate, vintaging of existing stocks was taken into account. Control costs were broken down into:

- Individual control costs
  - start-up / one-time costs
  - recurring capital costs
  - annual costs
  - salvage costs
- Societal costs
  - energy costs
  - other penalties
- Industry impacts
- Overall regulatory impacts

Summary of Initial Results

Based on this extensive analysis of the current uses of CFCs, we believe that substantial low cost reductions are available using currently available technologies. While our data are not conclusive, and some of the reductions might not be realized, our initial analyses suggest that reductions up to 30 percent of current use might be possible without chemical substances and at a cost of about 0.15 dollars per kilogram. Let me emphasize that these reductions do not assume that new technologies or new chemical substitutes become immediately available. Reductions are achieved by such methods as alternate test gases, increased recycling and product substitutes. For example:

- CFC-11 used in rigid polyurethane foam packaging could be replaced in most applications by fiber-based materials.
- CFC-113 used in metal degreasing and electronics cleaning could be more effectively captured and recycled.
- CFC-11 used in centrifugal chillers could be recycled instead of released during servicing.
- CFC-12 used in mobile air conditioning to test for leaks could be replaced by other test gases.
- Halon 1301 released during tests of total flooding systems could be reduced by better system design
- CFC-12 used in hospital sterilization could be replaced by units which recycle the CFC.
- CFC-12 blown food packaging products could be replaced by paper packaging.

A longer list of possible steps to reduce current uses of CFCs and Halons is attached to this testimony.

The estimates we have been able to develop for costs of meeting a particular regulatory goal could change and should be viewed with caution. Our initial work so far suggests that a freeze at 1986 levels on CFC-11 and CFC-12 would result in cumulative costs between 1990 and the year 2000 of around $200 million.

The above cost estimates assume that individual firms implement available least cost reduction steps. However, not all low-cost reductions identified in our data base will be taken. Moreover, some identified costs could not be accurately estimated, and we, of course, cannot account for likely hidden costs and complications. In addition, some controls are incompatible. In contrast, certainly not all possible methods of reduction have been identified. Some are impossible to know, given the proprietary nature of their technologies. In other cases, market incentives will unleash innovation, which leads to new or lower cost controls. New options will undoubtedly be developed as cost incentives rise.

Beyond the initial short-term period (up to 3 years), additional reductions would be possible as new capital replaces old capital. Moreover, beyond seven years, if the price of existing chemicals rises significantly, additional reductions through chemical substitutes might be possible. Thus, any costs of meeting a regulatory goal will be extremely sensitive to the timing of implementation. In addition, the certainty of the regulatory goal would also strongly influence movement toward low cost reductions to CFCs and Halons.

Summary of Benefits from Reductions

The costs presented in these analyses can be compared to the benefits of stratospheric ozone protection. By reducing growth in CFC and Halon emissions, the control strategies are projected to reduce stratospheric ozone depletion, thereby reducing future increases in harmful ultraviolet radiation. In addition, reductions in CFC and Halon emissions should slow global climate change. It should be clearly noted that CFCs themselves do not have a primary harmful effect on humans. Instead, it is their secondary effects - their ozone-depleting qualities - that potentially impact our environment and consequently affect humans.

The effects of stratospheric ozone depletion and global climate change were analyzed in our recently completed risk assessment: "Assessing the Risks of Trace Gases that Can Modify the Stratosphere". The report, which was recently reviewed by the Agency's Science Advisory Board, also presents the models used to compute health and environmental effects due to ozone depletion.

Using these models, we find that control strategies lead to substantial reductions in harmful effects. For example, under the "no controls" scenario, with increased growth in CFCs (i.e., 2.5% annual growth), the number of skin cancer cases in the U.S. could increase by 105 million (there are currently 500,000 skin cancers annually), and the number of premature deaths by 2 million among the population alive today and born through 2075 (i.e., these numbers include possible cancer cases and deaths that may occur well into the 22nd Century). These calculations assume no changes in population behavior, societal behavior, medical knowledge, diagnoses, treatment or prevention through this time period. For a global freeze on current CFC production levels beginning in 1990, 92 million excess skin cancer cases and 1.8 million deaths could be averted. For a 50% global phasedown on world CFC production by 1996, 97 million excess skin cancer cases and 1.9 million deaths would be averted. This assumes that developing nations continue using CFCs in ever increasing amounts. While more difficult to quantify, controls on CFCs would lead to other benefits to human health and welfare and the environment. These benefits appear to include reduced damage to the eye and the immune system, reduced degradation of outdoor polymers, reduced formation of ground-level ozone, reduced contribution to global warming and sea level rise, and reduced perturbations to terrestial and aquatic ecosystems.

Chemical Substitutes

In addition to our identification of existing control options for CFCs, we have initiated a special effort to explore promising new chemical substitutes for CFCs. We have convened a panel of internationally recognized chemists, engineers, and toxicologists from industry and academia to explore questions of technical and economic feasibility as well as safety of new compounds that are less harmful to stratospheric ozone. The panel, chaired by Dr. Richard Lagow of the University of Texas, included representatives from the United States, Japan, the United Kingdom, and the Federal Republic of Germany.

The panel has met in two sessions -- in Washington, DC in February 1987 and in California in April 1987. The panel concluded that it is the absence of a market for higher priced chemicals -- not technical or environmental barriers -- that is slowing the commercialization of new, less harmful chemicals. The panel stated that it felt that only worldwide governmental regulations could provide sufficient incentives to commercialize the new chemicals. If regulation of the existing chemicals increased their price sufficiently, the panel projected that some of the new chemicals could be marketed within six years.

The panel also concluded that the most promising new chemicals -- FC134a and CFC-123 -- can be produced using a variety of technologies that are available throughout the world. They rejected the possibility that a monopoly would develop and predicted that these new chemicals will be competitively produced and priced. A representative from E.I. DuPont de Nemours & Co., Inc. stated that at full-scale commercialization, the company would offer FC134a at a price between two dollars per pound and four dollars per pound. The price of CFC-12 is approximately 70 cents per pound.

Representatives from the automobile and refrigeration industries expressed a preference for a "drop-in" chemical such as FC134a, even if it were priced several times higher than existing CFCs, because these chemicals are a small component of equipment cost and would require less changes in refrigeration equipment. However, representatives of the rigid foam insulation industry expressed concern that they could not afford major price increases for CFC-11. CFC-11 is priced at 60 cents per pound and its potential alternative, CFC-123, is estimated by DuPont to cost $1.25 per pound to $2.50 per pound once full-scale commercialization is achieved. The panel identified the most promising substitutes, the likely range of costs, and the time necessary for commercial production.

Conclusion

As part of our effort to evaluate the impact of possible reductions of ozone-depleting chemicals, we have developed an extensive data base on potential costs of limiting CFCs and Halons. Refinement of the data base continues. Present information indicates that low cost reductions of up to 30 percent appear possible in the short term given currently available technologies. Additional reductions are possible after three years even in the absence of new chemicals. According to current estimates, if toxicity problems are not encountered, FC134a, a possible substitute for CFC-12, could be available in five to six years if the price of CFC-12 rises sufficiently.

SUBSTITUTES FOR COMMERCIAL CHLOROFLUOROCARBONS

by

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Chlorofluorocarbons were introduced in the 1930s as "miracle compounds" which replaced other much less satisfactory materials as refrigerants and for other uses. At the time the refrigerants used were such things as ammonia, sulfur dioxide and methylene chloride all of which posed numerous toxicity problems and most were candidates for explosions as well when mixed with oxygen. Furthermore, such species as ammonia (NH_3), sulfur dioxide (SO_2), methylene chloride (CH_3Cl), also cause extensive corrosion in refrigeration systems.

Even though there appear to be problems with the six commercially available chlorofluorocarbons with the massive use of this day and time for refrigerants, blowing agents, foaming agents, cleaning agents and a growing use in the microelectronics industry of such chlorofluorocarbons, the situation if such things as ammonia were currently used for refrigeration, other uses, etc. would pose much more threat of environmental damage. The inexpensive ammonia and SO_2 are still used in refrigeration systems in a few remote parts of the world. The currently available chlorofluorocarbons certainly do have the advantage of not too high toxicity, no particular problems with explosions and flammability, few corrosion problems and a number of other advantages.

One of the most basic problems to be dealt with on any proposed alternative substitute, improvement or new material to serve these many uses is the extremely inexpensive ("cheap") technology that has developed over the years for manufacturing chlorofluorocarbons. While some fluorocarbons commonly sell for $20.00 a pound and in bulk quantities seldom get below \$4.00 a pound, chlorofluorocarbons (Freons) are available at about \$0.75 a pound and the usage is so heavy that many of their common applications are only economic in that price vicinity. The situation is a result of the fact that the Swarts process uses the very inexpensive starting materials anhydrous hydrogen fluoride and chlorocarbons obtained directly from chloro alkali plants producing chlorine gas. Chlorine gas produced directly from chloro alkali cells costs on the order of \$0.08 to \$0.11 a pound.

1) CHLOROCARBONS CHLOROFLUOROCARBONS

$$CHCl_3 \xrightarrow[\text{SbCl}_5\text{/antimony fluorides}]{\text{HF}} CHF_2Cl$$

(any chlorocarbon may
be used including
carbon tetrachloride)

SWARTS REACTION

As previously indicated, the chlorocarbons such as chloroform, carbon tetrachloride, and chlorinated ethanes are extremely inexpensive. These materials are manufactured by direct chlorination on the site of chloro alkali plants such as those of Dow Chemical in Midland, Michigan and Freeport, Texas which sit on salt domes and uses their source of chlorine salt (sodium chloride). Thus chlorocarbons can be in the range of \$0.10 to \$0.30 per pound.

The bulk of the process, neglecting antimony pentachloride/fluoride catalysts proceeds using anhydrous hydrogen fluoride. Although the price of anhydrous hydrogen fluoride may be as much as \$0.50 a pound currently, in the recent past it has been as low as \$0.30 per pound. The Swarts process usually gives a mixture of chlorofluorocarbons, creating a problem that has been solved fairly efficiently by massive and expensive separation plants based on cryogenic and distillation processes to separate mixtures of compounds into readily marketable and fairly pure chlorofluorocarbon materials. This extremely inexpensive process gives commercial chlorofluorocarbon products in the $0.75 per pound price range. Hydrogen fluoride is a very low energy material containing a 132 kcal/mol hydrogen-fluorine bond and synthesis using hydrogen fluoride requires much less energy than a process to make chlorofluorocarbons using fluorinating agents, electrochemical fluorination or other higher energy materials.

The Swarts process with chlorofluorocarbons produces six major compounds. Namely, fluorocarbons 11, 12, 22, 113, 114 and 115 which have the structures:

CFC-11	(CCl_3F)
CFC-12	(CCl_2F_2)
CFC-22	($CHClF_2$)
CFC-113	($C_2Cl_3F_3$)
CFC-114	($C_2Cl_2F_4$)
CFC-115	(C_2ClF_5)

Produced along with these structures are two or three structures which are less useful compounds which also result from the Swarts reaction. Industry and many technologies have found very volatile inert chemical compounds that have useful properties for numerous applications. It should be noted that these compounds simply evolved from the Swarts process that manufacture and availability at such a low price preceded the development of applications in most cases for the compounds. Chlorofluorocarbons have major importance in industrial processing in the U.S. and worldwide.

Thus one of the greatest difficulties with respect to price of chlorofluorocarbon compounds containing hydrogen which are manufactured is the fact that they must compete with respect to price with products from the Swarts reaction. In general, the Swarts reaction does not lead to hydrogen-containing chlorofluorocarbons in high yield.

Another advantage of the Swarts reaction to produce chlorofluorocarbons is that there are major chemical compounds which are important articles of commerce in the chemical industry which are by-products and/or derived from the Freon type processes. For example, a nice synergistic technology is the manufacture of tetrafluoroethylene, the monomeric precursor for the polymer polytetrafluoroethylene (Teflon). The monomer is manufactured from chlorofluorocarbons according to the following pyrolysis process and dechlorination of chlorofluoromethane:

$$2)\quad 2\ CHF_2Cl \xrightarrow[\text{Platinum tube}]{700^\circ} \underset{\text{tetrafluoroethylene}}{F_2C = CF_2} + HCl$$

This and other by-products also play a role in the low price of industrial chlorofluorocarbons. Teflon, the polymerization product of tetrafluoroethylene, for example, can be purchased in the $3.00 per pound price range as a result again of the Swarts reaction technology.

Please note here this observation: there is simply not an economic incentive for invention research and manufacture of alternative chlorofluorocarbons at the present time. One must be artificially created. Further the Swarts process is extremely difficult to beat.

Findings of the CFC Committee

April 24, 1987

I. FC-134a

Reasons to expect that FC-134a will be a good substitute for CFC-12

1) Since FC-134a contains no chlorine, it is expected to have an insignificant ozone depletion potential.

2) FC-134a has thermodynamic/physical properties very similar to CFC-12, making it an attractive substitute for CFC-12 that would probably not require major redesign of hardware or user applications. The cooling capacity of FC-134a should be comparable to CFC-12.

3) In preliminary applications testing, it appears that FC-134a may be a close substitute for CFC-12, requiring minimal capital investment and minor equipment redesign.

4) Available toxicological data (acute and subchronic) suggest a very low order of general toxicity.

5) Several viable pathways for the synthesis of FC-134a have been identified.

6) Many companies and nations throughout the world will be able to make FC-134a; a monopoly on production will not be possible.

7) Since the use of FC-134a requires less reengineering, retooling, and other investment than other possible alternatives and is a small component of the equipment cost, refrigeration and mobile air conditioning markets should be able to pay a significant multiple of the current price of CFC-12.

8) FC-134a is predicted to have a short atmospheric lifetime relative to CFC-12. Consequently its build up in the troposphere and greenhouse capacity should be quite small.

Uncertainties about FC-134a that need resolution

9) The toxicological data for FC-134a are incomplete.

10) At this time there is no cost-effective lubricant known to the panel that fully meets the performance characteristics needed by users.

11) At this time there is no consensus on the optimum process for the manufacture of FC-134a.

12) Detailed performance data in most applications are still lacking.

13) The atmospheric decomposition products and the ultimate fate of FC-134a are not known with certainty.

Critical steps that must be taken to expedite successful commercialization of FC-134a

14) Development of a strong regulation which restricts chlorofluorocarbons is essential to create a commercial market for FC-134a.

15) Early initiation of full scale chronic inhalation testing is necessary to expedite the process of commercialization.

16) Research to identify compatible lubricants should be accelerated.

17) Adequate quantities of FC-134a should be provided immediately to users for testing and evaluation.

II. CFC-123

Reasons to expect that CFC-123 would be a good substitute for CFC-11

1) CFC-123 is predicted to have a low ozone depleting potential.

2) Available data (acute and subchronic toxicity) suggest a low order of general toxicity.

3) CFC-123 has similar physical properties, making it an attractive substitute for CFC-11. CFC-123 appears to have many of the desirable characteristics for foam blowing.

4) Preliminary applications testing indicates that CFC-123 is a good substitute for CFC-11.

5) Many companies throughout the world will be able to manufacture CFC-123; therefore a monopoly on production will not be possible.

6) Test quantities for applications are available now.

Uncertainties about CFC-123 that need resolution

7) The magnitude of the market in which CFC-123 should substitute as a blowing agent is unclear given the availability of other substitutes in the market for CFC-11 and the expected cost and performance characteristics of CFC-123.

8) The thermal conductivity of CFC-123 is approximately 10 percent greater than CFC-11. Sufficient testing has not been completed to ascertain the overall effect of this property on comparative insulating properties of CFC-123 and CFC-11. Lower insulation properties could make it less attractive to compete with other substitute insulating materials.

9) The atmospheric decomposition products of CFC-123 and their fates are not known with certainty.

Critical steps that must be taken to expedite successful commercialization of CFC-123

10) Available quantities of CFC-123 should be made available to users for performance testing in some applications.

11) It is necessary to perfect the chemical mix of foam blowing process using CFC-123.

III. CFC-132b

Reasons to expect that CFC-132b will be a good substitute for CFC-113

1) Acute toxicity testing revealed no toxicity problem.

2) Due to its solvent capabilities, CFC-132b may be a good substitute for CFC-113 in metal cleaning.

3) CFC-132b is too aggressive a solvent for cleaning electronics components that contain plastics; identification and development of compatible plastics could remove this obstacle.

4) Many identifiable methods are possible to produce CFC-132b and the price should be competitive because it can be manufactured from low cost intermediates.

Critical steps that must be taken to expedite successful commercialization of CFC-132b

5) The electronics industry needs to be involved in the development and adoption of compatible plastics. Specifications need to be investigated.

6) Metal cleaning applications should be demonstrated.

International Panel on Alternative Chemicals Statement

Long-lived CFCs, particularly CFC-11, CFC-12, and CFC-113, have been identified as potential threats to the environment. The most immediate concern is stratospheric ozone depletion, but additionally they contribute to the greenhouse effect.

Society needs chemicals to replace these CFCs in their valuable uses such as air conditioning, refrigeration, industrial cleaning, and building insulation. Substitutes such as FC-134a, CFC-123, and CFC-132b have been identified that appear capable of meeting many of these needs. These chemicals are expected to present a much lower risk to stratospheric ozone depletion potential and greenhouse warming than the chemicals they replace. We have developed a list of candidate materials, should they be needed, for further investigation.

We recommend that governments around the world design regulations which create strong incentives for commercialization of safe materials. Because society cannot afford to be without substitute chemicals, governments should also sponsor research to reduce technical uncertainty and to enhance our knowledge of chemical substitutes, particularly for research into those chemicals that are not now under active consideration by chemical companies. Additionally, we strongly support immediate implementation of conservation measures to reduce emissions from existing chlorofluorocarbon applications.

ORNL Research Programs
related to
Chlorofluorocarbon (CFC) Alternatives

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Testimony to the
Subcommittee on Hazardous Wastes and Toxic Substances
Subcommittee on Environmental Protection
U.S. Senate

Joint Hearings on Stratospheric Ozone Protection and
Substitutes for Ozone-Depleting Chemicals

May 13, 1987

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*Operated by Martin Marietta Energy Systems, Inc., under contract no. DE-AC05-84OR21400 with the U.S. Department of Energy.

ORNL RESEARCH RELATED TO CFC ALTERNATIVES

Current Activities and Future Needs

Background

Chlorofluorocarbons (CFCs), the family of chemicals commonly referred to as Freons (duPont trade name) have been linked to ozone depletion, a well-publicized environmental concern. Upper atmospheric ozone protects the earth's surface from harmful radiation. According to the Environmental Protection Agency's (EPA) recently completed risk assessment, depletion of the ozone layer could result in increased skin cancers, suppression of the human immune system, and damage to crops and aquatic life - representing a serious threat to public health and the environment.

Steps are being taken toward worldwide action on CFC emissions. International negotiations have started under the auspices of the United Nations Environmental Programme (UNEP) on a global protocol for CFC controls, with a UNEP goal of completing negotiations in 1987. The U.S. position in the talks advocates a freeze at 1986 production levels of all fully halogenated CFCs (such as CFC-11 and CFC-12) as a first step, and an eventual 95% phase-out of the compounds as a long-term goal, presumably over a 15- to 20-year period. The U.S. position is based, in part, on the risk assessment reports submitted to EPA's Science Advisory Board.

EPA also has a mandated schedule for proposed rulemaking in 1987 for further U.S. domestic CFC regulations. This is the result of a court agreement stemming from a suit brought against EPA by the National Resources Defense Council (NRDC) in 1984.

CFC Uses and Control Impacts

However, CFCs have found widespread uses and restrictions should be considered carefully. CFCs are used in the production of goods and services estimated at more than $28 billion annually and involving 715,000 jobs. Restrictions on the use of certain CFCs without adequate work to develop and evaluate the technical options could also have serious consequences for energy consumption in the U.S., particularly for refrigeration, air conditioning, and heat pump applications and insulation materials.

Such energy-related uses accounted for about 63% of the CFC-11 production (47,300 metric tons out of 75,300 metric tons) and 77% of the CFC-12 production (104,600 metric tons out of 135,000 metric tons), plus 100% of the CFC-22 production (108,700 metric tons).

Policy options like mandatory controls and production caps may not be feasible in these application sectors. Technically, currently available technologies (e.g. using ammonia or hydrocarbon refrigerants or using conventional absorption equipment) could be used but would probably not be readily acceptable in the market. Furthermore, according to the Alliance for Responsible CFC Policy, the impact of a U.S. ban on CFCs could result in an annual energy penalty equal to 9-12 billion gallons of fuel oil (1.3-1.7 Quads), due to the forced use of less energy-efficiency technologies. Additional problems with currently available alternatives are their higher first costs and operating costs and in some cases their undesirable properties (toxicity, flammability, carcinogenicity and high operating pressures). Therefore, substantial research is needed to develop safe alternative technologies with equal or better energy-efficiency.

Federal/DOE Role

Developing alternative technologies involves long-term generic research representing an appropriate area for Federal involvement. Other reasons for federal involvement are the possibility of accelerating introduction of alternative technologies into the marketplace; the issue of foreign competition; and the need to develop alternative technologies that are energy efficient.

The Department of Energy (DOE) is the appropriate Federal agency to lead research on alternative CFC technologies for the refrigeration and insulation industries. Since 1977, DOE's Office of Buildings and Community Systems (OBCS) has worked successfully with these industries in bringing new technologies into the market place. And already there is some industry support for DOE to undertake a similar role on CFC Alternatives technology.

Relevant DOE R&D

Some of the current DOE energy conservation research activities related to the CFC issue include:

> Absorption Cycle Technology - The absorption cycle employs non-CFC refrigerants such as ammonia or water. It is heat-operated and converts gas, oil, or waste heat into refrigeration, cooling, or heating effect through a chemical process (conventional CFC-based equipment uses mechanical compression). Although the absorption cycle has been used for refrigeration and air conditioning for many years, its share of these markets in the U.S. has declined due to low efficiency and cost competition from CFC-based chillers and refrigeration systems. However, advanced high-efficiency absorption technology is one of the major technology areas of DOE's Building Equipment Research (BER) Program at ORNL, an area with strong U.S. HVAC industry participation.

In Japan, about 80% of all large commercial buildings are now cooled with absorption chillers. The Japanese are presently clear leaders in the production of this equipment. The technical innovations from the DOE research program could help the U.S. HVAC industry meet the increasing challenge of foreign competition in this technology area.

Advanced Insulation - Insulations are critical to energy efficiency in many sectors of the economy including appliances, buildings, transportation, and industrial processes. For several years, ORNL has conducted a broad-scope research program covering both existing commercially available insulating materials and new insulation concepts. One particular advanced material concept involved a fumed silica powder encapsulated in a vacuum bag (much like the vacuum-packed coffee currently available in the supermarket) for insulation in appliances such as refrigerators and freezers. This project was a technical success, demonstrating that it was feasible to achieve insulating values 2-3 times that of the polyurethane foams currently being used in appliances.

Several other concepts have been proposed and should be investigated, including vacuum microspheres and aluminum-coated glass fibers in a vacuum. A future, expanded effort will be required to assess these concepts and their potential applications in buildings and equipment. The availability of advanced high-performance insulations could have a major impact on the technical feasibility of reduced use of chlorofluorocarbons (CFCs) for blowing the foam insulations currently used in these applications.

Novel Thermodynamic Cycles - Many alternative cycles can operate without the use of CFC working fluids - typically employing helium, hydrogen, or air - and are currently limited to special applications such as cryogenics. Cycles in this group include Brayton, Stirling, and Vuilleumier (VM). All three have been researched or technically evaluated for refrigeration and space conditioning applications by DOE, other national research organizations such as Gas Research Institute and Electric Power Research Institute, and by some foreign R&D establishments. However, to date the substantial budgets required to develop these concepts did not appear warranted on the basis of energy efficiency benefit alone. These cycles certainly deserve further consideration in the search for potential replacements for CFC-11 and CFC-12 and possibly CFC-22 systems (longer-term option).

Fluid Substitutes and Recovery Technology - In addition to these non-CFC technology examples, we have a major ongoing research effort on non-azeotropic refrigerant mixtures (NARMs) which could contribute in the substitute fluids area, a project on aging of foam insulations, and a small exploratory research effort on CFC recovery/recycling techniques.

As these examples illustrate, there is a range of long-term and near-term technology options that should be considered. We have been working with EPA, our industry contacts, and DOE to formulate a comprehensive, balanced R&D plan which would address these options in a systematic way.

CFC Alternatives R&D Program

We recommend a DOE coordinated government-industry program on CFC alternatives with three major objectives:

- to identify and develop a range of alternatives that can reduce CFC emissions,
- to provide in-depth comparative evaluation of alternative approaches and energy impacts for each major CFC end-use application, and
- to provide improved estimates of the research effort and implementation time required for these technologies.

The program will take advantage of initial survey, screening, and evaluation work on alternatives by EPA and extensive input from industry for initial scoping of R&D needs. It will provide not only a systematic approach for new technology development activities, but also a focus for existing research applicable to the CFC issue (as described previously). This integration should facilitate technology transfer to the private sector.

Development of substitute chemicals to replace CFCs - Research would focus initially on adapting existing systems to newly identified substitute chemicals without major equipment modification or redesign. FC-134a as a replacement for CFC-12 in refrigeration and air conditioning applications is the best current example. A 3-4 year period of toxicological testing remains before this is established as an acceptable compound. Other issues associated with this substitute include low process yield and high accompanying waste output, high cost, and the need to develop a compatible lubricant. Therefore, this 134-a substitute, while promising, still entails substantial technical risks and other uncertainties that may not be completely resolved for several years and should not be relied upon without backup alternatives.

Similar uncertainties are associated with the newer CFCs that might be used in the production of foam insulation materials, such as substitution of CFC-123 for CFC-11.

DOE would work closely with the chemical, materials, and refrigeration industries by conducting screening analyses to identify promising new chemical substitutes and by testing them for performance impacts like energy efficiency and system reliability. Exploratory research would also be conducted to identify new refrigerant mixtures (NARMs, azeotropes) which could be used as chemical substitutes. If needed, DOE could expand its activities by conducting detailed field evaluations and toxicological tests.

Development of enhanced containment, recovery and recycling practices- This research would focus on mid-term solutions, such as developing better techniques to contain CFCs in manufacturing processes and refrigeration systems servicing, by developing better recovery practices, and by developing recycling and/or treatment techniques for final disposition of CFCs. To date most attention has focused on new products and has not addressed CFC inventories in the existing stock of insulation materials, appliances and HVAC equipment (so called "banked emissions") or CFC field usage applications. The useful life of these materials and equipment is such that retirement and disposal of the existing stock will require many years. Techniques will also be needed for proper disposal of CFCs in discarded material or scrapped equipment, even when practical substitute chemicals or alternative non-CFC technologies are developed for new products.

Development of alternative non-CFC technologies - Research would be conducted to develop mid- to long-term solutions, such as advanced non-vapor compression refrigeration cycles (reverse Stirling, advanced absorption, desiccants, thermoelectric, chemical and magnetic heat pumps) which do not use CFCs.

Additional research would be conducted on advanced insulation systems and materials (evacuated panels, ultra-fine particles, evacuated hollow ceramic spheres) that do not rely on CFC blowing agents and foams, but which have high energy efficiency.

The DOE program activities would be closely coordinated with EPA. In previous meetings with EPA, it was found that DOE would complement the EPA program effort by taking the lead in R&D on longer-range technical alternatives for energy-related uses. ORNL's near-term activities on this new program include an energy impact assessment and obtaining extensive industry and EPA input for preparation of a more detailed R&D agenda and Program Plan document.

Until we know from the scientific studies the extent of reduction in CFC emissions that will ultimately be required, it would seem prudent that work in all three research areas be pursued in parallel. The longer-term options such as new cycles would probably be implemented if drastic reductions or complete elimination of certain CFCs prove necessary. However, these options involve more development time and should be pursued as insurance against future disruptive economic or social changes and energy impacts, even if smaller reductions in CFC emissions are called for in the initial international protocol or U.S. regulations. The larger the emission reduction goals and the more extensive the list of CFCs affected, the more important the role of new technology.

Resource Requirements and Schedule - As presently envisaged, this is likely to be the start of a multiyear DOE program of 4-5 years increasing to a budget level of $1 million per year or more. The exact scale and timing would be recommended at the end of the first phase evaluation and scoping activities. A funding level of $500K in FY-88 should be adequate for the survey, assessment and initial scoping work.

Closing Remarks

We share the concern about this global environmental threat. We feel that it is important to take a positive step and provide the CFC-dependent industries with a technical support incentive for early identification and development of CFC alternatives technology. The coordinated government-industry program on CFC alternatives I have described would offer industry the technical expertise and assistance of the DOE National Laboratories and an opportunity for cost-shared collaborative research projects. I hope our input and future contribution can help stimulate industry and government cooperation in this area. We will be glad to furnish additional details or to assist you in any other way in getting proper attention directed toward this R&D aspect of the CFC issue.

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TESTIMONY
OF
ELWOOD P. BLANCHARD
GROUP VICE PRESIDENT, CHEMICALS AND PIGMENTS DEPARTMENT
E. I. DU PONT DE NEMOURS AND COMPANY
BEFORE
THE COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
OF THE
UNITED STATES SENATE

MAY 13, 1987

Mr. Chairman, members of the Committee, my name is Elwood Blanchard. I am the Group Vice President of the Chemicals and Pigments Department of the Du Pont Company. I am appearing before your Committee to provide our views concerning the questions raised in your letter of May 4, 1987. In your letter you asked for our views on the availability of nonozone depleting substitutes or alternatives for the fully halogenated chlorofluorocarbons, or CFCs as they usually are called.

Before I address the specific questions raised by the Committee, I would like to review briefly with you the value of CFCs to society. As you will see, I am raising this issue because we all must be aware that CFC uses are not trivial and if we must limit their use, such limitation should be thoughtful in regards to the time needed to bring forward suitable replacements and thoughtful in regards to the U.S. competitive industrial position. I believe it is safe to say that our society as we know it, could not operate without substances which perform the functions now performed by CFCs. CFCs touch all of our lives each day. We use them for heating and cooling our homes. We use them to cool our automobiles and other transport. They are used for the preservation of foodstuffs either through direct freezing or in refrigeration. They are used in the manufacture of foams for insulation and for cushioning in autos and furniture, as solvents in high technology industries such as computer manufacture and in the medical field as sterilants and to clean dialysis machines, and I could go on.

The CFCs in commerce today are more expensive, on a per pound basis, than other commercially available materials that could be used in their place, where such substitutes are available. Notwithstanding their unit cost, CFCs have stood the test of five decades of use and continue to be preferred components in the applications I have just mentioned, because of their outstanding performance characteristics and especially because of their low toxicity and low flammability.

Because of these outstanding performance and safety properties, there is significant investment in durable goods such as home refrigerators using current CFCs. If unwarranted restrictions are placed on the availability of current CFCs before acceptable substitutes are available or without providing that existing equipment, such as refrigerators, can be maintained, a homeowner could be forced to replace a refrigerator rather than recharge it with less than a dollar's worth of CFC-12.

Thus, great care needs to be taken to assure that the response to the CFC issue neither unnecessarily disrupts our economic system or lifestyle nor introduces risks more immediate and significant than those which could be caused by the current CFCs. This caution, we believe, is particularly appropriate because none of the identified substitutes are commercially available, and if they were, would be a drop-in for the principal, essential uses of the current fluorocarbons.

We believe, however, that the need for substitutes may arise as a result of our shared concern for protecting the environment. Without going into detail on the science, I can summarize our view by saying that there is no crisis today, and control of CFC emissions growth will prevent any future crisis. There is no imminent danger to man or the environment. However, we do believe that the various model calculations indicate that uncontrolled growth in global emissions of fully halogenated CFCs would pose a risk to stratospheric ozone at some point in the future. Considerable scientific investigation is still needed to better understand the potential impact of CFCs and other trace gasses on the stratosphere. Until this can be done, we believe it is prudent to limit emissions of trace gasses, including CFCs, that have ozone depletion potential.

Such limitations may well lead to a need for substitutes, and at Du Pont, we have renewed our attempts to develop substitutes with lower ozone depletion potential. We also have undertaken programs to identify practices and technology that will reduce emissions.

We believe that the only effective long-term solution to the ozone depletion issue is some form of global agreement to control future CFC emissions. The experience with the U.S. aerosol propellant ban should teach us that unilateral domestic action without agreement on a global approach will not resolve this issue, but will have the potential to cause a U.S. loss of world market share for goods and services and further increase trade deficits. We do not believe that unilateral domestic regulation or laws to control CFCs can be crafted in a way that will avoid a reduction in United States worldwide competitiveness. Therefore, we believe that the appropriate international role for the U.S. Administration is to lead the UNEP negotiations toward an agreement with the other major industrial countries to cap the growth in emissions of the fully halogenated CFCs. The delegates should also seek agreement on a way of determining what scientific findings should trigger further controls, if needed.

We would urge the Congress to exercise restraint and support a binding global solution rather than to legislate unilaterally. EPA needs support and effective oversight, not early legislation pushing it to take steps that could undermine its ability to get the needed multinational agreement. We have considered what would happen if the U.S. adopted a total ban and the use of CFCs in the rest of the world continued to grow at a rate of 5% per year. Under this scenario, following a U.S. reduction, world emission levels would return to 1986 levels within eight or nine years, thus unilateral action even if taken to the extreme of a domestic ban would not, in the long run, result in lower global emissions.

In addition, we believe that such unilateral action could lead to a situation where U.S. products containing potential CFC alternatives would not be acceptable in export markets because of their higher cost and incompatibility with foreign products. Domestic consumers would pay more for their refrigerators, air conditioners and cars which would be available not only from domestic sources but also from offshore suppliers. As a result, our balance of payments could be adversely affected. As shown above, unless a global solution is developed, the U.S. consumer would be asked to pay more for products containing CFC substitutes but there would be essentially no benefit to the environment. It would be impossible to deal with the export economy via trade controls. Similarly, restrictions to protect domestic market would necessarily address both CFCs and downstream products, would be bureaucratically cumbersome, and would ultimately be ineffective. The result could be that U.S. industry is sufficiently disadvantaged that alternatives R&D could not be supported financially, destroying even the illusory chance of a future competitive advantage.

We are supportive of a global effort and have begun to respond to what we perceive is needed from the private sector. We have publicly supported a global effort to address the growth in CFC emissions and have clearly communicated to our customers both our commitment and the need for their serious attention to this issue. We have formed a task force to review known emission reduction technology and to seek better ways to reduce or eliminate emissions. The task force will work with our customers to develop practices which will reduce unnecessary emissions. Finally, we are working to complete programs to develop alternatives which have lower ozone depletion potential.

Du Pont currently produces approximately 25 percent of the worlds CFCs, including the fully-halogenated CFCs of concern, i.e., CFC 11, 12, 113, 114, 115, and Halon 1301 as well as those of low ozone depletion potential like CFC 22 and 152a, along with other specialty products and blends. We serve all of the major CFC markets worldwide, i.e., refrigeration, blowing agents, and cleaning agents, along with several smaller applications. We are committed to meeting the needs of those markets in the future, if possible.

In your request you asked a variety of questions about our alternatives research. We have available two comprehensive discussions of that effort, and we have attached both to this testimony for inclusion into the record. The first (Attachment A)* is a letter written to Congressman Henry Waxman in reply to a series of similarly specific questions, and the second (Attachment B) is a discussion paper on the issue prepared primarily for customers. The following excerpts from those documents address several of your questions.

We have not identified candidates outside of the generic class of fluorocarbons which we believe will possess the requisite chemical, physical and safety characteristics. Thus, our work has focused on fluorocarbons that have no ozone depletion potential or at a minimum, significantly lower ozone depletion potential. It should be made clear that not all of the candidates have zero ozone depletion potential but, in all cases, we believe they have such low potential that they would not pose an unacceptable risk to stratospheric ozone. Furthermore, the candidates would be rapidly and harmlessly removed from the lower atmosphere by natural processes. If controls on their emissions were deemed necessary as a result of further research, the atmosphere could quickly recover. More specifically, we believe that although CFC-22 is an existing product with substantial uses, it has an ozone depletion potential of about 5% of that of CFC-11 and must be considered as a part of the solution rather than as part of the problem.

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*The attachments to this statement have been retained in committee files.

We have also identified a number of additional candidate compounds with what we believe have similarly favorable ozone depletion numbers. However, none of these substitutes are available today without further development work by us and by our customers.

The efforts to identify substitutes began in the mid-1970's and was completed by about 1980. In the course of that work, we conducted acute toxicity tests, application studies, physical property measurements, and scouting for possible manufacturing processes. By 1980, it was clear that such products could not be made to compete with the major existing CFCs in the marketplace. The major development efforts were curtailed, and the focus shifted to our ongoing basic research in fluorine chemistry, with an eye toward commercially useful developments.

However, in 1986 the picture changed with our conclusion that some precautionary limits had become appropriate, and our belief that such limits will eventually justify production of more expensive and somewhat less satisfactory alternatives.

The status of our research is summarized below:

CFC-21; CFC-31; CFC-133a Research on these substances was discontinued when preliminary toxicity testing indicated that they would be more toxic than we considered acceptable for compounds in general distribution.

CFC-124; FC-125; FC-143a Early research indicated that the chemistry of these compounds would make a commercial production process extremely difficult. In addition, the substances do not have physical properties that make them very attractive candidates for commercial use. With these two major strikes against them, we have not pursued an active research effort on these compounds and, therefore, cannot speculate as to whether one could eventually successfully develop a commercial process.

CFC-123; FC-134a; CFC-132b; CFC-141b The chemical and physical properties of these substances make them viable candidates for additional research.

CFC-123 is presently available in very small, noncommercial quantities as an unrefined by-product of an existing manufacturing process. This substance possesses physical properties similar to those of CFC-11. However, significant applications testing will have to be conducted to determine whether it could be employed commercially in applications where CFC-11 is now employed. Toxicity testing is not yet complete and will have to be completed before an estimate of suitability could be given. In addition, a commercially viable process has not yet been identified and developed. Until this can be done, it is difficult to provide a good estimate of how long it will take us to develop commercial quantities. The compound is included in our active phase two research discussed earlier, however, and we believe, if all technical hurdles are successfully overcome, a minimum estimate would be approximately five years.

CFC-141b has been identified as another potential substitute for CFC-11. A developmental process exists for this compound, but flammability and likely high cost have minimized interest in attempting commercialization. In addition, further toxicity testing is required before marketing could be undertaken. As a result of discussions with users, future development work will await direct comparison with CFC-123. Again, five years is a minimum estimate for commercialization if hurdles can be overcome and market demand materializes.

FC-134a is potentially a very good replacement for CFC-12 for refrigeration applications, based on its physical and chemical properties. Since it contains no chlorine, it does not have any ozone depletion potential. Toxicity testing now underway on this substance must be completed before a decision to market the material could be made. Work is also underway to identify the optimum process route to make this material commercially. Again, five years is a reasonable estimate of a minimum time needed to complete the full program.

CFC-132b has been identified as a substance that could find use in some CFC-113 solvent applications. However, we do not believe that this compound is a good replacement for CFC-113 in all applications, especially where a mild, stable solvent is required, as in electronics. We have studies underway and planned that will help us to identify and quantify the potential market for this compound. Additional toxicity testing on this substance is underway to determine whether it would be suitable for use in solvent applications. In this regard, we have just received preliminary results from our toxicologists conducting a 90 day inhalation range finding study of CFC-132b. In an interim sacrifice at 45 days they have observed microscopic testicular damage at each of the three exposure levels employed in the test. I wish to underscore that these results are preliminary and we will not have definitive findings or recommendations for further study until after this rangefinding study is completed and our experts have had a chance to fully analyze the data. Nevertheless, this demonstrates the need to move carefully in evaluating the suitability of any substitute for an existing product. We will, of course, provide you with the results of this study when it becomes available.

As with the substances discussed above, additional process development work is needed if this material is to be made commercially available. We estimate that two to three years of further development will be required before a commitment to commercialization can be made, should there be adequate demand.

We emphasize that of the potential substitutes we have discussed for the major uses, only CFC-22 is currently available. Assuming that the market demand for currently available CFCs or their substitutes will continue to grow, almost any regulatory scheme must provide for a transition. We do not have a ready solution to all of the problems which will be encountered. None of the generic alternatives is commercially viable in the marketplace today because there is no demand for them. However, we believe that an international agreement on emission limits will stimulate the needed development, commercialization and use of such alternatives. Recognizing this potential need, we have placed renewed research emphasis on the development of substitutes with lower ozone depletion potential to try to be ready when our customers need these substitutes.

In addition, we believe that there are compounds, such as CFC-113, which have unique and essential uses and for which we have not identified suitable substitute candidates. A system of emission limits would be particularly applicable to continued use of these essential compounds. In fact, many users of CFC-113 have already taken steps to prevent losses to the atmosphere.

All of our efforts are being approached in a spirit of cooperation with our customers. We have met with CFC users in all market areas both to obtain guidance in setting our own R&D priorities and to plan cooperative efforts. It is very difficult, however, to determine in detail for any new product what condition of price and demand will be required to support commercialization. In this case, even the manufacturing process is not yet determined, and accurate prediction is impossible. There is no way of knowing now whether a new product could be sufficiently cost-effective to permit customers to remain in business.

Similarly, it is virtually impossible to predict the impact on prices of restrictions on the current CFCs. A restriction on the demand side would actually reduce prices, whereas restricted supply might lead to an increase. Scaling back of production would undoubtedly alter the ratio of fixed to variable costs, significantly increasing both unit cost and hence sales price. Only a detailed analysis of the form of regulation (in addition to its stringency) would allow such predictions. Even then, the actual market response remains a major undefined uncertainty. In practice, successful businesses are often the ones which make more accurate guesses about the future. The key word, therefore, is caution.

If there is one message I would like to leave with you from my testimony, it is that we as a nation need to pull together to develop workable solutions to this problem. Last September when we concluded that it was prudent to act on the issue, we called for a limit on emission growth for CFCs and for a regulatory negotiation to develop a consensus U.S. position. EPA concluded that it would not invoke a formal Regulatory Negotiation process because the time for action was too short and because it did not believe it could convene a group of manageable size. Although we believe Regulatory Negotiation should have been undertaken to gather the necessary facts to reach a sound decision, the Agency has not been idle: it has been active in the UNEP process; it has been visiting other nations trying to get them to do their share; it has prepared a draft risk assessment which is under review by its Science Advisory Board; and it has convened various expert groups with representation from diverse interest areas in an attempt to develop informal but meaningful inputs on issues that need to be addressed in CFC regulations. In this way, the Agency appears to be seeking a rational path through the maze of problems of further regulation of CFCs. Hopefully, this process will demonstrate that any regulation must provide flexibility in meeting future needs.

In conclusion, we believe that there is no imminent crisis that demands unilateral regulation. We are committed to support continued research and agree that the findings in Antarctica and elsewhere should be fully explored to insure that these observations are not indicators of a broader problem. We are committed to continue our work to develop substitute products for the fully halogenated CFCs so long as we see a potential market demand. Specifically, we intend to determine whether the candidates can meet the needs of the marketplace for low toxicity, functional performance and cost effectiveness. Although we have not yet solved all the problems of how to produce safe substitutes for existing fully halogenated CFCs, we believe we have identified promising candidates for many applications and our confidence in our technical strengths leads us to believe we will be able to develop commercially viable methods to produce them.

bcc: Ozone Steering Committee R.M.Heine

CH-1 REV 7-80

E. I. DU PONT DE NEMOURS & COMPANY
INCORPORATED
WILMINGTON, DELAWARE 19898

CHEMICALS AND PIGMENTS DEPARTMENT

May 28, 1987

The Honorable Robert T. Stafford
United States Senate
SH-133 Hart Senate Office Bldg.
Washington, D.C. 20510-4501

Dear Senator Stafford:

This is written in response to questions posed to the witnesses at the hearing of May 13, 1987, relating to substitutes for fully halogenated CFCs. You asked that the witnesses provide for the record their comments on the following questions:

> "First, why are you today advocating a status quo with respect to CFCs when you said in 1983 that we should act if an analysis of actual measurements showed there was depletion of the ozone shield"?
>
> "Second -- and please answer this only after responding to the first question -- please provide the Committee with a list of every scientist known to the Alliance who has stated in a peer-reviewed presentation that either there is no ozone depletion or that CFCs are not responsible."

Before responding to this, we have a brief comment on a statement made by Dr. Irving Mintzer of the World Resources Institute in his oral testimony. We understood him to say that he had been convinced by Du Pont personnel that safe substitutes could be made available for the major CFCs in less than five years. We do not believe that Dr. Mintzer has properly interpreted our statements. We have stated that it may be possible to complete process development work, toxicity testing, and construction of a plant capable of producing commercial quantities of alternative compounds that could be substituted for currently available CFCs in some -- but not all -- uses in a minimum of five years. However, for this to happen there could be no setbacks, and in fact, the process could take longer. In addition, we do not know what Dr. Mintzer meant when he said that we convinced him that such products would be "safe." At this point our information on the safety of potential substitutes is incomplete. Please refer to my written testimony as it regards the state of knowledge concerning the health and environmental effects of the potential substitutes.

At Du Pont, we believe the 1983 statement: "Obviously, if analysis of actual measurements, such as ozone trend analysis, tells us a problem is developing, we should act," is as valid today as it was in 1983; and we still agree with that position. In fact, we have recommended that there be a global control in CFC emissions even though there is no current scientific data that shows that a problem is developing. We do not believe that we have taken a position which advocates that the status quo be maintained.

We have actively supported adoption of a protocol to control global emissions through the UNEP negotiations. In addition, we also recommended that the EPA undertake the regulatory negotiation process to develop a fair and effective U.S. approach to accomplish emission controls and to develop a consensus position that could be used in international negotiations.

In view of the growth in the use of CFCs that we have seen over the last several years, we believe global emission limits will in fact produce incentives that will stimulate the development of alternatives to fill the growing demand for products with the desirable properties of CFCs.

We have also renewed our investment in time and money to pursue the development of alternatives to the fully halogenated CFCs. As a part of this development program, we have met with our customers to explore their needs and enlist their participation in the development of substitutes.

Thus, to reinforce what I said during my testimony on the 13th of May, we believe that our actions do not support the status quo but rather are the kind of leadership that is needed to protect both the environment and the U.S. economy.

With regard to the second question posed to the Panel, we have compiled the following information. There is ample peer-reviewed evidence that there has been no persistent change in global column ozone amounts. Our comments on ozone measurements relating to this evidence will be divided into the four categories or classes that are most often discussed:

- Total ozone measurements from ground-based instruments,
- Profile ozone measurements from ground-based instruments,
- Ozone measurements from the satellite-based SBUV instrument, and
- Antarctic ozone phenomenon.

Copies of the documents cited, or in some cases, where the documents are lengthy, the relevant pages of the documents are enclosed.

TOTAL OZONE MEASUREMENTS FROM GROUND-BASED INSTRUMENTS

When one considers the length of the data record, the reliability of the measurements and the relevance to environmental effects -- total ozone amounts control the amounts of UV-B reaching the ground -- the best set of ozone data available is that from the Dobson spectrophotometer network. The network consists of 36 ground-based stations that have been in almost continuous operation for nearly 30 years.

Supporting evidence for the statement that there has not been a significant decrease in global ozone column amounts is available from two types of documents: consensus assessment reports and peer-reviewed journal articles. In addition, there is Congressional testimony that is supportive of this. A list of statements from the more recent documents follows:

Consensus Assessment Reports

- Atmospheric Ozone 1985, Assessment of Our Understanding of the Processes Controlling its Present Distribution and Change, World Meterological Organization Global Ozone Research and Monitoring Project - Report No. 16 (WMO Report No. 16), pages 20 and 819.

  "Global trend estimates of total ozone determined from the Dobson spectrophotometer network indicate little overall support for a statistically significant trend during the 14-year period 1970-1983."

  This is a summary point in Chapter 14, "Ozone and Temperature Trends." Panel members for that chapter were:

  K. Labitzke, Co-Chair
  A. J. Miller, Co-Chair

J. Angell	C. Mateer
J. De Luisi	B. Naujokat
J. Frederick	G. Reinsel
J. Logan	G. Tiao

  The statement was then brought forward to Chapter 1, "Introduction and Science Summary." Panel members for that chapter were:

R. T. Watson, Chair
R. A. Cox
S. C. Wofsy
V. A. Mohnen
A. F. Tuck
R. A. Plumb
J. Frederick
C. Leovy
G. Brasseur
H. I. Schiff
J. E. Harries
M. J. Molina
J. A. Pyle
H. S. Johnston
A. J. Miller
K. Libitzke
V. Ramanathan
W. B. DeMore
N. Husson
D. L. Albritton
R. Stolarski
M. Geller

The entire report was reviewed by the "Peer Review Panel and Agency Liasons" listed below.

M. Geller, Co-Chair
R. T. Watson, Co-Chair
D. L. Albritton
H. Bauer
G. Brasseur
R. A. Cox
P. Crutzen
W. B. DeMore
D. H. Ehhalt
J. E. Frederick
R. Gammon
A. Ghazi
R. F. Hampson
J. E. Harries
N. Husson
H. S. Johnston
N. P. Krull
K. Libitzke
J. Mahlman
M. B. McElroy
A. J. Miller
V. Mohnen
M. Molina
R. A. Plumb
J. Pyle
V. Ramanathan
F. S. Rowland
H. I. Schiff
R. S. Stolarski
N. Sundararaman
N. D. Sze
A. F. Tuck
P. Usher

- Report of The Eighth Session of the Coordinating Committee on the Ozone Layer, Nairobi, 24-28 February 1986. A list of the participants (Annex II to the document) is enclosed. The following is a statement from the "Science Summary."

  "Statistical analyses for trends in globally averaged total ozone using data from the Dobson spectrophotometer network for the period 1970-1984 do not show a trend that is statistically different from zero (e.g. -0.7 percent ± 0.8 percent per decade and -0.3 percent ± 0.9 percent per decade)."

Peer-Reviewed Journal Articles

- Hill, W. J.; Oehlert, G. W.; and Reinsel, G. C.; "Trend Analysis Sensitivity Studies of Dobson Total Ozone Data Through 1984," J. Geophys. Res., 91, 14,515-14,520, 1986. This is the most recent update on analysis of measurements of total column ozone for trends -- other publications are referenced in that paper. The following statement is presented in the summary:

> "Through 1984, the total ozone trend estimates are -0.26 percent ± 0.92 percent per decade and -0.70 percent ± 0.82 percent per decade since 1970 based on the TD and FD [two methods of analysis] methods, respectively. Neither estimate is statistically significant when compared with the ±2σ limits."

- Oehlert, G. W., "Trends in Dobson Total Ozone: An Update Through 1983," J. Geophys. Res., 91, 2675-2679, 1986. To our knowledge, this is the only peer-reviewed publication containing evidence for a significant decrease in ozone after 1970. As stated in the abstract, the decreasing trend was primarily the result of abnormally low values during early 1983. Thus, there was no indication of a developing problem. Furthermore, as shown in the reference cited immediately above, when the analysis was updated to include 1984 data, the trend was not significantly different from zero. Also, as stated in the paper by Angel et. al. cited below, the abnormally low ozone values observed during late 1982 and early 1983 were probably caused by natural phenomenon. The abstract from the Oehlert paper follows:

> "We estimate the trends in Dobson total ozone records from 1970 through 1983, using ozone data from 1964 through 1983. These estimates range from -0.31 percent/decade ± 0.49 percent/decade for unadjusted data to -1.10 percent/decade ± 0.47 percent/decade for data adjusted for instrument interventions and the solar cycle. The negative trends are primarily the result of abnormally low total ozone values in the northern hemisphere during early 1983."

- Angel, J. K.; Korshover, J.; and Planet, W. G.; "Ground-based and Satellite Evidence for a Pronounced Total-Ozone Minimum in Early 1983 and Responsible Atmospheric Layers," Monthly Weather Review, 113, 641-646, 1985. A statement from the conclusions follows:

> "In conclusion, on the basis of this analysis, it is almost certain that the anomalous ozone decrease in late 1982 was real and was mainly, if not entirely, due to natural rather than anthropogenic phenomena."

Congressional Testimony

Although this is not peer-reviewed, it is responsive to your question.

- Testimony of Dr. A. J. Calio, Under Secretary for Oceans and Atmosphere, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, before the Subcommittee on Environmental Pollution and the Subcommittee on Hazardous wastes and Toxic Substances of the Committee on Environmental and Public Works, United States Senate, on May 14, 1987. A statement from page three of the testimony is:

  "In terms of ozone-trends observations, there is no compelling evidence in the existing ground-based and satellite data sets of a chlorine-induced ozone depletion."

PROFILE OZONE MEASUREMENTS FROM GROUND-BASED INSTRUMENTS

There are peer-reviewed publications stating that there are indications of statistically significant negative trends in ozone amounts in the middle to upper stratosphere and that the CFC/ozone theory is consistent with this result. However, model simulations of the atmosphere, which incorporate the CFC/ozone theory, as well as the effects of changes in the atmospheric concentrations of other trace gases, indicate that ozone decreases in the upper stratosphere would be compensated by increases at lower altitudes. The net result is virtually no net change in calculated total ozone. There is no evidence that there would be significant environmental effects resulting from ozone decreases in the middle to upper stratosphere as long as there is no net change in column ozone. Research in this area remains at an exploratory stage.

OZONE MEASUREMENTS FROM THE SATELLITE-BASED SBUV INSTRUMENT

Recently there has been discussion of unpublished analysis of data from the satellite-based SBUV instrument which indicates decreases in global ozone amounts since November 1978. Based on the analysis presented below, we see no compelling evidence resulting from satellite-based SBUV data that CFCs have caused ozone depletion.

- No analyses of SBUV data indicating global ozone decreases have been published in the peer-reviewed literature.

- A peer-reviewed publication (Fleig, A. J.; Bhartia, P.K.; and Silberstein D. S.; "An Assessment of the Long-Term Drift in SBUV Total Ozone Data, Based on

Comparison with the Dobson Network," Geophys. Res. Lett., 13, 1359-1362, 1986.) shows results indicating an increasing bias between ozone amounts measured by the SBUV instrument and those measured by 41 ground-based instruments. A conclusion of that paper is: "Until such a separation can be done it would not be unreasonable to increase the SBUV total ozone values by 0.38 percent per year before analyzing the SBUV total ozone measurements."

- Since ground-based measurements provide evidence that ozone amounts vary over time scales from days to 11 years, the 6 to 8 year data record (much of the science community has not even had access to the more recent data) from the satellite is too short to separate trends from natural fluctuations.

- Even if ozone amounts have decreased since November 1979, there is evidence that this is likely not due to CFCs. Photochemical model simulations that take into account observed changes in trace-gas concentrations (methane, carbon dioxide, nitrous oxide, and CFCs) indicate that changes in column ozone amounts should have been insignificant since 1979. If these models were significantly underpredicting the effect of CFCs, I would also expect them to underpredict the amount of ClO (chlorine monoxide) in the stratosphere since ClO is the key chlorine-containing compound in the CFC/ozone depletion theory. Comparisons of actual measurements of ClO amounts and model calculated values reported in WMO Report No. 16 on page 606 shows that this is not the case. A more recent measurement of ClO is consistent with the earlier measurements (Brune, W. H. and Anderson W. G., "In Situ Observations of Midlatitude Stratospheric ClO and BrO," Geophys. Res. Lett., 13, 1391-1394, 1986).

In addition, we call your attention to a letter from Mr. John F. Murphy, Assistant Administrator for Legislative Affairs, NASA, in response to questions asked by the Honorable Henry A. Waxman in which he expressed views basically consistent with ours regarding the meaning of SBUV data. The questions and the response relate to statements about the SBUV data made by Dr. D. Heath of NASA Goddard Space Flight Center. Several points from that letter follow:

"1. The trend quoted by Dr. Heath of 0.5-1.0 percent/year ozone loss is at the limit of accuracy/uncertainty of the satellite instrument.

2. In the upper stratosphere, Dr. Heath's decrease in ozone disagrees with the reported increase from the SME satellite.

3. The worldwide Dobson network shows no statistically significant trend in ozone over the last two decades. The global average ozone measurement by the Dobson network for 1985 is within 1-2 percent of the value for 1960.

4. The Dobson network does show a decrease in ozone from 1979 to 1985, due in large part to the fact that ozone in 1979 (the starting year for the Nimbus-7 data) was unusually high. Because of the natural fluctuations in ozone, it will always be possible to find limited time periods over which ozone shows a trend.

5. The trend reported by Dr. Heath is nearly an order of magnitude larger than that predicted to have occured due to increasing chlorofluorocarbons (CFCs). If the Heath trend is shown to be correct, it cannot be ascribed to CFCs within our current framework of stratospheric chemistry."

ANTARCTIC OZONE PHENOMENON

The Antarctic "ozone hole" phenomenon has raised many doubts regarding our understanding of atmospheric ozone and the reliability of photochemical models as forecast tools. We concur with the statement on page 4 of the paper "Stratospheric Ozone: NOAA's Current Research and Plans and a Summary of the State of the Science" prepared by Dr. D. L. Albritton and attached to the Testimony presented by Dr. Calio during the Senate Hearing on this issue on May 14, 1987. The statement is:

- "Because the current theories of the 'ozone hole' require the unique physical features of the region, the failure of the 'standard' global ozone-depletion theories to predict its occurance does not necessarily imply that these theories have major shortcomings regarding their predictions in other regions."

These "standard" ozone depletion theories "predict" that there is no imminent hazard if CFC emissions do not increase significantly. A summary statement from page 19 of WMO Report No. 16 is:

- "Time dependent scenarios were performed using one-dimensional models assuming CO_2, CH_4, and N_2O annual growth rates of 0.5 percent, 1 percent, and

> 0.25 percent, respectively, in conjunction with CFC growth rates of 0 percent, 1.5 percent and 3 percent per year. The ozone column effects are relatively small (≤3 percent over the next 70 years) for CFC increases of ≤1.5 percent per year, but with a CFC growth rate of 3 percent per year the predicted ozone depletion is 10 percent after 70 years and still rapidly increasing."

CONCLUSION

We believe that the above information adequately addresses your questions. I would like to close with a restatement of our position, which is solidly based on the science.

Although we continue to believe that no immediate hazard to health or the environment exists from current levels of CFC emissions, the wisdom of permitting continued growth must be weighed against the existing inability of the science to specify a safe, long-term growth rate. Resolution of this and other key scientific uncertainties in the ozone issue and greenhouse effects could take decades; therefore, we have concluded and continue to believe that it would be prudent to limit worldwide emissions of CFCs while science continues to work to provide better guidance to policymakers.

Sincerely,

Elwood P. Blanchard
Group Vice President

MM/GAH/tp
Enclosures
CC: Members of Environmental Protection
Subcommittee and Hazardous Wastes
Toxic Substances Subcommittee

(CC: NO ENCLOSURES)

STATEMENT OF

ROBERT F. TRAFLET
PRESIDENT
FLUORINE PRODUCTS DIVISION
ALLIED-SIGNAL INC.

Before a Joint Hearing of the
Senate Subcommittees on Environmental
Protection and Hazardous
Waste and Toxic Substances

May 13, 1987

ROBERT F. TRAFLET TESTIMONY

THANK YOU. MY NAME IS ROBERT TRAFLET. I AM PRESIDENT OF THE FLUORINE PRODUCTS DIVISION OF ALLIED-SIGNAL INC., AND I APPRECIATE THE OPPORTUNITY TO MAKE A BRIEF STATEMENT ON THE CHLOROFLUOROCARBON/OZONE DEPLETION CONTROVERSY.

ALLIED-SIGNAL RECOGNIZES THAT UNRESTRAINED GROWTH OF CFCS AND THE RELATED UNCERTAINTIES AS TO THEIR ATMOSPHERIC IMPACTS COULD ULTIMATELY LEAD TO UNACCEPTABLE LEVELS OF OZONE DEPLETION. WE BELIEVE PRUDENT ACTION IS WARRANTED. BECAUSE THIS PROBLEM IS GLOBAL IN NATURE, IT REQUIRES A GLOBAL SOLUTION. WE ARE PLEASED TO NOTE THE APPARENT PROGRESS BEING MADE UNDER THE AUSPICES OF THE UN ENVIRONMENT PROGRAM TO ACHIEVE INTERNATIONAL CONSENSUS, ALTHOUGH WE HAVE MAJOR CONCERNS ABOUT THE TIMING AND MAGNITUDE OF THE PROPOSED CONTROL MEASURES.

CONTROLLING CFC PRODUCTION INTERNATIONALLY AT OR NEAR EXISTING LEVELS GOES A LONG WAY TOWARD MITIGATING ANY POTENTIAL ATMOSPHERIC PROBLEMS. WHEN YOU ADD TO THIS THE POSSIBLE EFFORTS BY INDUSTRY IN CONSERVATION AND RECOVERY, THE IMMINENCE OF ANY POTENTIAL CONCERN ABOUT PUBLIC HEALTH LESSENS DRAMATICALLY. IN ADDITION, WE BELIEVE SUCH INTERNATIONAL CONTROL BY ITSELF WILL PROVIDE THE NECESSARY INCENTIVE TO DEVELOP AND TEST ENVIRONMENTALLY-SAFE ALTERNATIVES, GIVEN A REALISTIC TIME FRAME. FORCED REDUCTIONS ARE NOT NEEDED.

NOTE: Attachments to this statement have been retained in committee files.

A MAJOR CONCERN THAT WE HAVE WITH THE UNEP PROPOSAL, AS REPORTED, IS ON THE TIMING AND MAGNITUDE OF FORCED REDUCTIONS FOLLOWING A PRODUCTION CAP AT OR NEAR EXISTING LEVELS. FORCED REDUCTIONS IN THE EC CAN BE EASILY AND QUICKLY ACHIEVED BECAUSE A SUBSTITUTE FOR ONE OF THEIR MAJOR USES - AEROSOLS - ALREADY EXISTS. THE U.S. BANNED AEROSOLS IN 1978 - AN ACTION NOT FOLLOWED BY MOST EUROPEAN NATIONS. FORCED REDUCTIONS IN THE U.S. SIMPLY CANNOT BE ACHIEVED IN THIS TIME FRAME BECAUSE THE SUBSTITUTES ARE NOT AVAILABLE. AND REDUCTIONS, IF IMPLEMENTED, WOULD CAUSE SEVERE ECONOMIC DISLOCATIONS. ASIDE FROM THE ONGOING CONSERVATION AND RECOVERY EFFORTS, THE ONLY NEAR-TERM ALTERNATE TO CFCS IS TO RETURN TO THE USE OF SUCH CHEMICALS AS AMMONIA, SULFUR DIOXIDE, METHYL CHLORIDE AND HYDROCARBONS. ALL THESE CHEMICALS PRESENT SERIOUS OFFSETTING HEALTH, SAFETY, ENVIRONMENTAL AND ENERGY LOSS PROPERTIES.

ALLIED-SIGNAL MANUFACTURES CFC 11, 12, 22, 113 AND 114. THESE COMPOUNDS ARE USED IN A WIDE RANGE OF APPLICATIONS INCLUDING AUTOMOTIVE AND RESIDENTIAL AIR CONDITIONING, FOOD FREEZANTS, STERILANTS FOR MEDICAL USE, SOLVENTS FOR THE SEMI-CONDUCTOR INDUSTRY, FOAMS FOR ENERGY-EFFICIENT INSULATION AND FOR FOOD PACKAGING. THIS BUSINESS REPRESENTS APPROXIMATELY 30 PERCENT OF OUR CHEMICAL SALES.

THE INVITATION TO TESTIFY ASKED US TO ADDRESS THE AVAILABILITY OF NON-OZONE DEPLETING SUBSTITUTES FOR FULLY-HALOGENATED CFCS. AT THIS TIME, WE HAVE NO SUBSTITUTES ON THE SHELF AND READY TO GO.

IN 1974, WHEN THE ROWLAND-MOLINA THEORY WAS ADVANCED CONCERNING THE POTENTIAL EFFECT OF CHLORINE-CONTAINING COMPOUNDS ON THE OZONE LAYER, ALLIED-SIGNAL INTENSIFIED THE ONGOING SEARCH FOR NEW CFCS AS POSSIBLE REPLACEMENTS FOR CFC-11, CFC-12 AND CFC-113. IT IS IMPORTANT TO EMPHASIZE THAT CFC-11, CFC-12 AND CFC-113 WERE SUCCESSFUL PRODUCTS DUE LARGELY TO THEIR SAFETY AND EFFECTIVENESS. THESE CFCS ARE NON-IRRITATING, NON-EXPLOSIVE, NON-FLAMMABLE, NON-CORROSIVE, LOW IN TOXICITY AND EXTREMELY STABLE. IN FACT, IT IS THIS VERY STABILITY WHICH ALLOWS THESE CFCS TO REACH THE STRATOSPHERE.

SINCE 1974, WE HAVE STUDIED APPROXIMATELY 65 COMPOUNDS (DETAILS ATTACHED IN OUR RESPONSE TO REP. WAXMAN); ONLY THREE MAJOR CANDIDATES REMAIN.

OF THESE THREE, FC-134A AND CFC-123 OFFER THE BEST CHANCE OF MARKETPLACE ACCEPTANCE AND COMMERCIAL SUCCESS. FC-134A WOULD HAVE ITS PRIMARY USE AS A SUBSTITUTE FOR CFC-12 IN MOBILE AIR CONDITIONING. CFC-123 WOULD HAVE ITS PRIMARY USE AS A SUBSTITUTE FOR CFC-11 IN FOAM-BLOWING APPLICATIONS. IT IS BY NO MEANS CERTAIN, OF COURSE, THEY WILL BE SUCCESSFUL.

THESE TWO COMPOUNDS - COUPLED WITH ONGOING RECOVERY AND CONSERVATION EFFORTS IN CFC-113 APPLICATIONS, COULD REDUCE THE USAGE OF FULLY-HALOGENATED CFCS IN THE U.S. BY BETWEEN 25 PERCENT TO 40 PERCENT. HOWEVER, IT SHOULD BE STRESSED THAT EVEN IF ANY OF THE SURVIVING CANDIDATES TURNS OUT TO BE A SATISFACTORY SUBSTITUTE, IT WILL STILL REQUIRE BETWEEN SEVEN TO TEN YEARS BEFORE IT MIGHT BE COMMERCIALLY AVAILABLE.

OUR EFFORT TO FIND CFC SUBSTITUTES IS CONTINUING. IT INCLUDES PROGRAMS IN PROCESS CHEMISTRY, PROCESS DEVELOPMENT, TOXICOLOGY AND APPLICATIONS WORK FOR THE COMPOUNDS WE ARE EVALUATING. BUT THERE ARE IMPEDIMENTS TO QUICK COMMERCIALIZATION:

A) THESE COMPOUNDS HAVE BEEN EXAMINED BY US ONLY IN THE LABORATORY; WE HAVE BEEN ABLE ONLY TO PROVIDE LIMITED LABORATORY SCALE QUANTITIES TO END-USERS AND FOR ACUTE, SHORT-TERM TOXICOLOGY TESTS;

B) LONG-TERM TOXICOLOGICAL DATA ARE NOT YET AVAILABLE; AND TO THE BEST OF OUR KNOWLEDGE CANNOT BE FOR AT LEAST FOUR YEARS;

C) NO COMMERCIAL PROCESS EXISTS THAT WE KNOW OF TO MANUFACTURE THEM;

D) COMMERCIAL PRODUCTION OF THESE COMPOUNDS WILL LIKELY REQUIRE NEW FACILITIES AND HENCE COST MANY TIMES WHAT IT COSTS TO PRODUCE PRESENT CFCS;

E) THE COST AND PERFORMANCE OF THE SUBSTITUTE WOULD HAVE TO BE ACCEPTABLE TO END-USERS; BOTH DIRECTLY WITH USERS AND THROUGH THE CFC ALLIANCE, WE HAVE ACTIVE DISCUSSIONS UNDER WAY WITH MOTOR VEHICLE MANUFACTURERS, THE REFRIGERATION INDUSTRY, FOAM BLOWERS AND THE SEMI-CONDUCTOR INDUSTRY TOWARD THIS END.

F) WHILE THE CANDIDATE COMPOUNDS ARE BELIEVED TO HAVE LOWER OZONE DEPLETION POTENTIAL THAN PRESENT CFCS, THEY COULD CONTRIBUTE TO THE "GREENHOUSE" EFFECT AND SO THEMSELVES BECOME CANDIDATES FOR REGULATORY ACTION AT A LATER DATE;

G) TO BE COMMERCIALLY AVAILABLE, APPROXIMATELY SEVEN TO TEN YEARS WOULD BE NEEDED TO CARRY OUT THE FOLLOWING PROGRAM.

PROCESS RESEARCH - 2 YEARS

BECAUSE WE HAVE ONLY CANDIDATES AT THIS TIME AND NO FINISHED PRODUCT "ON THE SHELF", PROCESS RESEARCH NEEDS TO BE CARRIED OUT AT THE LABORATORY BENCH TO DETERMINE THE BASIC OUTLINE OF THE PROPOSED PROCESS (E.G., REACTION CONDITIONS OF TEMPERATURE, PRESSURE, MOL RATIOS, CATALYST CONCENTRATIONS AND LIFE, ETC.) AND TO ESTABLISH THE ULTIMATE QUALITY OF THE FINISHED PRODUCT.

PILOT PLANT CONSTRUCTION AND OPERATION - 1 YEAR

A PILOT PLANT IS NEEDED TO PRODUCE SUFFICIENT QUANTITIES OF MATERIAL FOR ALL REQUIRED TESTS AND FOR FIELD-TESTING BY END-USERS. THE PILOT PLANT WOULD HAVE TO BE OPERATED LONG ENOUGH TO "DEBUG" THE PROCESS AND TO ASSURE THE COLLECTION OF ENOUGH ENGINEERING DATA TO BE OBTAINED TO APPLY TO THE FINAL DESIGN OF A COMMERCIAL-SCALE FACILITY.

LONG-RANGE TOXICOLOGICAL STUDIES - 4 YEARS
BECAUSE OF THE IMPORTANCE OF SAFETY, ANY REPLACEMENTS WILL NEED TO UNDERGO LONG-TERM CHRONIC TOXICOLOGICAL STUDIES. SUCH STUDIES INCLUDE DETERMINATION OF ACUTE, SUB-ACUTE AND MUTAGENICITY PROPERTIES AND TAKE ABOUT ONE YEAR. THESE ARE FOLLOWED BY LIFE-TIME INHALATION AND REPRODUCTIVE STUDIES, WHICH TAKE ABOUT THREE YEARS.

CONSTRUCTION OF COMMERCIAL PLANT - 2 YEARS
TWO YEARS ARE NEEDED TO DO THE ENGINEERING DESIGN, TO OBTAIN PERMITS FROM THE APPROPRIATE REGULATORY AGENCIES, TO COMPLETE THE ACTUAL CONSTRUCTION, TO PREPARE OPERATING AND SAFETY MANUALS, TO HIRE AND TRAIN OPERATORS AND TO "DEBUG" THE NEW FACILITY.

THE ABOVE TIMETABLE ASSUMES, OF COURSE, THAT THE FINAL MATERIAL IS A HIGH-QUALITY PRODUCT, AND THAT ENOUGH MATERIAL CAN BE PRODUCED BOTH FOR TOXICOLOGICAL TESTING AND FOR USE IN DESIGNING NEW END-USER EQUIPMENT AND/OR RETROFITTING EXISTING EQUIPMENT. IT ALSO ASSUMES THAT THESE RESULTS ARE SATISFACTORY IN ALL PHASES OF DEVELOPMENT. TO PUT THIS INTO PERSPECTIVE, APPROXIMATELY 88,000 POUNDS OF MATERIAL WAS USED DURING THE TOXICOLOGY TESTING OF CFC-113. SIMILAR QUANTITIES WOULD BE NEEDED FOR EACH SUBSTITUTE TESTED.

SINCE THE LATE 1970'S, WE HAVE SPENT OVER $10 MILLION DIRECTLY ON THE SEARCH FOR SUBSTITUTES. IN ADDITION, WE HAVE SPENT ABOUT $5 MILLION IN SUPPORT OF ATMOSPHERIC RESEARCH ON OZONE DEPLETION BY FLUOROCARBONS. THIS INCLUDES OUR SHARE OF THE APPROXIMATELY $20 MILLION EXPENDED BY THE CHEMICAL MANUFACTURERS ASSOCIATION ON ATMOSPHERIC RESEARCH DURING THIS PERIOD. IN 1987, OUR EXPECTED EXPENDITURES FOR CFC SUBSTITUTES WILL BE OVER $3.0 MILLION. IT INCLUDES PROGRAMS IN PROCESS CHEMISTRY, PROCESS DEVELOPMENT, TOXICOLOGY AND APPLICATIONS WORK FOR THE SUBSTITUTES WE ARE NOW EVALUATING. IT ALSO INCLUDES EFFORTS IN RECOVERY AND RECYCLING AND VARIOUS BLENDS.

MR. CHAIRMAN, MEMBERS OF THE COMMITTEE, ONE OF THE KEY QUESTIONS THAT WE UNDERSTAND YOU ARE SEEKING TO ANSWER IS WHY THE PRODUCERS HAVE NOT PROCEEDED TO COMMERCIALIZATION OF SUBSTITUTES. I WOULD LIKE TO ADDRESS MYSELF TO THIS QUESTION.

QUITE FRANKLY, THE MARKET HAS NOT DEMANDED SUBSTITUTES. DURING THE TIME WHEN THE AEROSOL BAN WAS BEING CONSIDERED AND WENT INTO EFFECT, THE PROJECTED RATE OF OZONE DEPLETION WAS EXTREMELY HIGH. AS A NATION, WE TOOK ACTION AND BANNED AERSOLS. WITHIN A FEW YEARS OF THE BAN NEW SCIENTIFIC DATA WAS EXAMINED BY THE NATIONAL ACADEMY OF SCIENCE, AND THE PERCEIVED THREAT TO THE OZONE LAYER WAS REPORTED TO BE NOT AS GREAT AS PREVIOUSLY THOUGHT. EVEN TODAY THE DEBATE CONTINUES. (SEE ATTACHED ANALYSES OF OZONE TRENDS). AS A RESULT OF THIS LESSENED CONCERN, THE MARKET FOR SUBSTITUTES WAS SIMPLY NOT THERE.

MR. CHAIRMAN, THE REAL QUESTION IS WHAT INCENTIVES ARE NEEDED TO SPUR DEVELOPMENT OF ALTERNATES? WE BELIEVE THAT LIMITING THE GROWTH RATES OF CFCS TO AT OR NEAR 1986 LEVELS IS SUFFICIENT INCENTIVE. FROM A BUSINESS PERSPECTIVE, THE REASON IS SIMPLE: SUCH A CONTROL ACTUALLY REPRESENTS A SIGNIFICANT REDUCTION IN SUPPLYING FUTURE DEMAND, WHICH IS ESTIMATED TO GROW AT ABOUT 3 PERCENT PER YEAR.

IF SUFFICIENT DEVELOPMENT TIME IS AVAILABLE, IF THERE IS A REAL NEED FOR THE PRODUCT, AND IF IT IS SAFE AND EFFECTIVE, WE CAN EXPECT TO SPEND THE $50 MILLION OR MORE REQUIRED, AND BE REASONABLY CERTAIN OF A FAIR RETURN ON OUR INVESTMENT. DURING THIS DEVELOPMENT PERIOD WE WOULD EXPECT THE COOPERATION OF OUR GOVERNMENT TO BE SURE THAT FOREIGN PRODUCERS DO NOT BENEFIT FROM THEIR LATE EXIT FROM THE AEROSOL MARKET AND FLOOD THE U.S. WITH AVAILABLE PRODUCT.

IN SUMMARY, WE BELIEVE AN INTERNATIONAL AGREEMENT ON THIS GLOBAL ISSUE IS THE ONLY SOLUTION THAT WILL PROVIDE REAL ENVIRONMENTAL PROTECTION AND WILL CAUSE THE LEAST ECONOMIC DISRUPTION. UNILATERAL U.S. ACTION WILL PROVIDE ONLY LIMITED ENVIRONMENTAL PROTECTION, WHILE MAKING U.S. INDUSTRY LESS COMPETITIVE. TIMING IS THE KEY. SINCE THERE IS NO IMMINENT DANGER, AN INTERNATIONAL AGREEMENT REDUCING THE GROWTH RATE OF CFCS TO AT OR NEAR 1986 LEVELS WILL, BY ITSELF, FURTHER MITIGATE ANY POTENTIAL ATMOSPHERIC PROBLEMS AND WILL PROVIDE THE NECESSARY INCENTIVES TO DEVELOP ALTERNATE COMPOUNDS.

PLEASE BE ASSURED OF OUR DEEP CONCERN WITH THE ISSUE OF OZONE DEPLETION AND OF OUR DESIRE TO BE RESPONSIVE. WE KNOW THAT MANY IN THE CONGRESS SHARE OUR DESIRE TO EXPEDITE THE DEVELOPMENT AND COMMERCIALIZATION OF ACCEPTABLE SUBSTITUTES. WORKING TOGETHER, WE BELIEVE THIS IS AN ACHIEVABLE GOAL.

THANK YOU.

DOW CHEMICAL U.S.A.

WILLARD H. DOW CENTER
MIDLAND, MICHIGAN 48674

Comments by The Dow Chemical Company to The Senate Committee on the Environment and Public Works and The Subcommittee on Hazardous Wastes and Toxic Substance's and The Subcommittee on Environmental Protection's Joint Hearings on Stratospheric Ozone Depletion and Substitutes for Ozone Depleting Chemicals

May 13, 1987

by

Hugh A. Farber, Ph.D. - Consultant

Introduction

The Dow Chemical Company is responding to this committee's request for information on carbon tetrachloride, methylene chloride, and methyl chloroform which we produce. We have tried to address most of the questions from this committee which relate to these products. In addition to these chemical specific comments, we have attached as an appendix a previous response to questions raised by Congressman John Dingell which reviews some of our other concerns with the ozone depletion issue and various regulatory considerations. We also attach comments by the Halogenated Solvents Industry Alliance (HSIA), of which we are a member, and whose comments before the House Subcommittee on March 26, 1987, we support.

We would like to commend this committee for recognizing that as it considers further legislative action, it must consider the total health, environmental and economic picture related to potential alternative materials. The ozone depletion issue cannot be addressed as a separate issue, for other health and environmental factors play a role in determining the suitability of whatever approach is taken to address these concerns.

General Comments

Before turning to the specific concerns raised by this committee, we must point out that we were surprised to see these three materials, and CFC-22, listed in the Senate proposals as materials considered for severe control. Carbon tetrachloride control automatically occurs as CFC-11 and CFC-12 are addressed, since it's only significant use is as a raw material for producing these two CFCs. Methylene chloride is so low in atmospheric residence time that all scientific reviews we have seen discount it as a potential ozone depletor. Indeed, it is more often considered an alternative for some uses to which the CFCs are applied.

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Methyl chloroform falls into a category of short lived halocarbons that may contribute a very small extent of whatever ozone depletion may actually occur. Thus, it cannot be forgotten but in reality, in today's environment, should still be considered part of the solution. This is because with a short residence time (about 6 years) only a small portion of that emitted can survive to reach the stratosphere. More important, however, is the correctability factor that such short lived halocarbons share. Thus, if a serious potential ozone depletion is supported by data not yet available, significant reductions in emissions result in a very rapid reduction in atmospheric burden as methyl chloroform would be scrubbed from the lower atmosphere over a short time frame. This is in contrast to the refractory halocarbons, which once emitted, apparently will survive to reach the stratospheric ozone area. Thus, methyl chloroform, and other materials with short residence times, can be considered favorable materials at this time and also offer a safety feature in case significant depletion of the ozone related to their emissions is supported by new data.

You asked for Dow's USA production of these three solvents since 1980. That information is as follows:

MM Lbs/Year

Year	Carbon Tetrachloride	Methyl Chloroform	Methylene Chloride
1980	167	386	299
1981	124	245	279
1982	113	295	259
1983	98	300	266
1984	106	327	272
1985	131	277	250
1986	169	321	239

It is obvious that Dow's U.S. growth trend for carbon tetrachloride is essentially flat, while both methyl chloroform and methylene chloride show a declining trend. The sales of these solvents represent between 2-3% of total Dow USA sales dollars in 1986. Direct and allocated capital associated with the manufacture of these products is about $380MM, and about 380 employees are involved in the manufacture, research and sales of these products.

The major commercial uses for these products are:

Carbon Tetrachloride	Methyl Chloroform	Methylene Chloride
Fluorocarbons	Metal Cleaning Coatings & Inks Adhesives Electronics Fluorocarbons	Chemical Processing Paint Removers Aerosols Urethane Foams

We will turn now to the questions dealing with potential substitutes for these three solvents, and will answer these questions on each material in a specific fashion.

Carbon Tetrachloride

Nearly all of the carbon tetrachloride we produce is used for production of CFC-12 and CFC-11. The fate of this chemical is directly tied to the future of two CFCs, and of course, there is no need to discuss substitutes for carbon tetrachloride. We also point out there are no new uses for carbon tetrachloride on the horizon, and we expect none to surface in the forseeable future.

Methylene Chloride and Methyl Chloroform - General Comments

Before discussing methylene chloride and methyl chloroform individually, there are some general comments applicable to both materials.

In contrast to the CFCs, where some possible alternatives have not been evaluated, all of the chlorinated materials with one or two carbons have been prepared and tested to varying extents. (See attached table). These are the materials that would be most likely to have physical properties similar to methylene chloride and methyl chloroform. We must emphasize that these two solvents, along with trichloroethylene and perchloroethylene, are the result of culling out the less likely candidates on the basis of chemical, physical, flammability or toxicity properties. We would not consider any of these other materials as suitable alternatives for most of the uses to which these four chlorinated solvents are widely applied. Indeed some of these materials were once used as solvents, e.g. chloroform and carbon tetrachloride, but were to a great extent replaced by one of the more favored four chlorinated solvents now broadly used.

Methylene Chloride

Methylene chloride has proven itself to be a low flammable, low toxicity, high solvency, economical solvent. Furthermore, since it doen't contribute to low atmosphere ozone levels, it is one of the few solvents exemptable from state plans to attain ambient air quality standards. It also has been judged by nearly all scientists to have such a short atmospheric residence time, that it doesn't really play a role in the stratospheric ozone depletion issue. Indeed, it has been considered, and is used as a substitute, for some uses in which CFC-11 has been traditionally employed, in these cases acting as part of the solution to whatever ozone depletion problem may exist or arise in the future.

It is hard to imagine an alternative chemical that would share all the favorable properties with methylene chloride. It is possible that one of the new generation CFCs, not yet available, may serve as a substitute in some uses. Otherwise, the non-CFC alternatives which we could envisage would be among the more flammable classes of solvents, creating potential hazards for the users. They would also contribute to ozone generation, creating additional problems for those areas of the country already facing great difficulties in complying with Federal air standards. It is almost a certainty however, that the costs for these other alternatives, whatever they may be, would be markedly higher than present costs for methylene chloride.

In addition to alternative solvent considerations, it would be misleading to not consider completely different technologies for performing some of the functions to which methylene chloride is applied. For example, although it seems unlikely and unnecessary, it may be possible to perform paint stripping with mechanical devices or high temperatures. Damage to the furniture, or cabinet, etc. would be hard to avoid and significant personal hazards would arise. However, this approach is possible. Perhaps certain coatings and adhesives could be applied without the use of a solvent. Other uses could possibly be addressed in a similar fashion. However, these technologies aren't acceptable today, and again, seem unnecessary to protect man or his environment.

Methyl Chloroform

Turning to methyl chloroform, we can state that many of the comments made about methylene chloride apply here as well. However, there are some significant differences.

Methyl chloroform is a low flammable, low toxicity, medium solvency, economical solvent. It is not considered a precursor to low atmosphere ozone generation and is exemptable from state plans to attain the Federal ambient air ozone standard. The role methyl chloroform plays in potential stratospheric ozone depletion is small, with a short residence time leading to ozone depletion factors reported as ranging from 0.06 to 0.15 compared to CFC-11 which is assigned unity. The importance of this low residence time was discussed in an earlier part of this submission, but must be emphasized once more.

We are unaware of another solvent available now or in the foreseeable future that could have a similar set of favorable properties when compared to methyl chloroform. There are solvents that have higher worker exposure standards. There are solvents that have lower ozone depletion factors. There are solvents that have lower flammability characteristics. However, there is no single solvent, or mixture of solvents, that has all of the properties ascribed to methyl chloroform. Indeed, most would be controlled as air pollutants and would be much more flammable. As with methylene chloride, methyl chloroform is one of the solvents that results from culling out the alternatives among the large family of low molecular weight chlorocarbons that might have been expected to have properties similar to the four large volume solvents used so widely today.

One of the biggest uses for methyl chloroform is the removal of greases, oils, and other foreign matter from a variety of substrates including metal, plastic, fabric, electronic parts, etc. In most of these areas there are already competitive solvents or processes. In addition, some of the new "soft" CFSs may work in some of these uses. Today, trichloroethylene, perchloroethylene, and CFC-113 are available alternatives for some of these cleaning areas. Of course, it must be pointed out that methyl chloroform has been favored as a replacement for some past uses of these alternative solvents because of some of the favorable properties mentioned above. However, these solvents do share the high vapor density and low flammability which allows them to be safe and economically used in vapor degreasing equipment. Vapor degreasing is a process wherein hot solvent vapor condenses on the material to be cleaned, then drains off carrying grease and soil with it. The equipment is designed to reduce solvent vapor losses by condensing solvent vapor and returning it to be reused over and over. Thus, vapor degreasing is, by design, a solvent recovery system in its own right. It should be emphasized that more flammable solvents cannot be used in this type of process. There are thousands of such operations in daily use throughout many industries in the United States.

Flammable solvents can be used in some non-vapor degreasing processes, and indeed are used today. All such materials are controlled under state air pollution control programs, and some of these users have already converted to the few exemptable solvents available, including methyl chloroform.

There are many other uses for methyl chloroform, and most of these have resulted from considering one or more of the favorable properties methyl chloroform possesses. For example, some coating operations require solvent-based paints, and there are severe restrictions placed in many industrialized areas on solvents not exemptable from air pollution regulations. The same comments can be made about methyl chloroform use in certain adhesives. Other uses are dependent on the ease with which methyl chloroform can be used in a safe fashion relative to flammability and toxicity concerns. Many of the consumer product uses are clearly dependent on the combination of favorable properties possessed by methyl chloroform, and whereas there are no doubt some uses in which other solvents would work, a price would be paid in potential increased hazards to the users. It does not seem necessary, or desirable, to pay that price when all the available health and environmental data, including ozone depletion potentials, are integrated.

Other Considerations

We have chosen not to attempt a response to questions dealing with what price and quantity are necessary to bring alternatives to these three solvents to commercial status. We have no such alternatives available to consider.

We also have not critically analyzed the price to which these three solvents will rise if production is frozen at 1986 levels or reduced by varying percentages as outlined in your request for comments. It is probable that, if carbon tetrachloride production is reduced due to CFC-11 and CFC-12 reductions, that Dow capabilities to economically produce other chlorocarbons, e.g. perchloroethylene, could be significantly distorted. The amount cannot be quantified, and resulting price increases on methylene chloride and methyl chloroform would be dependent on this change as well as market conditions. The latter could be impacted by our competitor's positions, for not all of them are significant producers of carbon tetrachloride and do not have the largely integrated facilities that Dow has at it's production sites.

If production of methylene chloride or methyl chloroform were held at 1986 levels, there would probably be a gradual increase in price to the consumer if demand were to increase since supply versus demand can have a significant impact. This cannot be quantified at this time.

If production of either or both of these materials were reduced by varying percentages, we would expect significant price increases in the lower percentage reduction scenario (20 percent) as all producers try to stay in business but operate plants at a more costly and lower utilization rate. With percentage reductions of 40 to 95 percent, production units would be abandoned. The surviving producers cannot be identified at this time. It is clear, however, that if demand became far in excess of supply, that prices would rise dramatically, even if cost-to-produce in remaining plants escalated in a more marginal fashion.

The above comments are, necessarily, general in nature since specific information is most difficult to obtain by prognostication. The comments are valid for both a national and international control program. However, if the U.S. were to take unilateral action, other factors would play a role in how U.S. producers, and more important, U.S. using industries would fare versus foreign competition on both the national and international scene. This subject has been the focus of several attempts by other groups, including the E.P.A., and we feel it is almost impossible at this time to predict the outcome with enough precision to be of more value than these general comments.

It seems certain that if the U.S. were to take unilateral action along the lines of any of these scenarios, that we would suffer a loss in our competitive position. Trade restrictions would be necessary to protect our U.S. industries, and the many jobs they furnish, from further imbalances in trade. Frankly, we have not yet tried to determine specific trade provisions, for it seems obvious that if there really is a problem with potential ozone depletion it is global in nature and must be addressed in a responsible and similar manner by all nations that produce and/or use these important chemicals. We believe, that if the U.S. proceeds unilaterally, we will be doing a disservice to our industries, the U. S. public, and the environment as well. If, in spite of these considerations, the U.S. does proceed unilaterally, it is obvious that some very complex issues must be considered relative to trade provisions and such issues are far beyond the scope of our present comments.

NOTE: Attachments to this statement have been retained in committee files.

	COMPOUND	TROPOSPHERIC O_3 CONTRIBUTOR	STRATOSPHERIC O_3 DEPLETOR	TOXICITY ESTIMATE	FLAMMABILITY ESTIMATE	BOILING POINT (°C)
CH_3Cl	Methyl Chloride	Low	Low	Med-High	High	Gas
CH_2Cl_2	Methylene Chloride	No	No	Low	Low	42
$CHCl_3$	Chloroform	No	No	Med-High	Very Low	61.2
CCl_4	Carbon Tetrachloride	No	Yes	High	None	76.7
C_2H_5Cl	Ethyl Chloride	Low-No	No	Low	High	Gas
$C_2H_4Cl_2$	1,1-Dichloroethane	Low-No	No	Low	Med-High	58
$C_2H_4Cl_2$	1,2-Dichloroethane	Low-No	No	High	Med-High	83
$C_2H_3Cl_3$	1,1,1-Trichloroethane	No	Low	Low	Low	75
$C_2H_3Cl_3$	1,1,2-Trichloroethane	?	?	High	Low	113.5
$C_2H_2Cl_4$	1,1,1,2-Tetrachloroethane	?	?	High	Low-None	130.5
$C_2H_2Cl_4$	1,1,2,2-Tetrachloroethane	?	?	High	Low-None	146.5
C_2HCl_5	Pentachloroethane	?	?	High	None	159.1
C_2Cl_6	Hexachloroethane	?	?	High	None	Solid
C_2H_3Cl	Vinyl Chloride	Yes	No	Med-High	High	Gas
$C_2H_2Cl_2$	Vinylidene Chloride	Yes	No	Medium	High	37
$C_2H_2Cl_2$	1,2-Dichloroethylene	Yes	No	Medium	High	48-60
C_2HCl_3	Trichloroethylene	Yes	No	Medium	Low	86.7
C_2Cl_4	Perchloroethylene	Very Low	No	Medium	None	121
C_3H_7Cl	Chloropropane	Low(?)	Low(?)	Med-High	Med-High	46.6
$C_3H_6Cl_2$	1,3-Dichloropropane	Low(?)	Low(?)	Med-High	Med-High	125
$C_3H_6Cl_2$	1,2-Dichloropropane	Low(?)	Low(?)	Med-High	Med-High	96.3
$C_3H_5Cl_3$	1,2,3-Trichloropropane	Low(?)	Low(?)	High	Med-Low	156.17

Higher chlorinated derivatives in the C_3 and C_4 series, if low in flammability, would be too high in boiling point to serve as useful solvents

HAF:03/09/87

STATEMENT OF
ROBERT L. JEANSONNE
VICE PRESIDENT AND GENERAL MANAGER
DIVERSIFIED PRODUCTS, KAISER CHEMICALS,
BEFORE
THE SUBCOMMITTEE ON HAZARDOUS WASTES AND TOXIC SUBSTANCES
AND
THE SUBCOMMITTEE ON ENVIRONMENTAL PROTECTION
OF
U.S. SENATE
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
MAY 13, 1987

Mr. Chairman, members of the Subcommittees, good morning. My name is Robert Jeansonne. I am a vice president of Kaiser Chemicals, a division of Kaiser Aluminum & Chemical Corporation. I appreciate the opportunity today to outline for you our views on our shared concerns with respect to stratospheric ozone depletion, the contributions of chlorofluorocarbons (CFCs) to this situation and the proposed means for alleviation or control of anticipated adverse effects.

We became concerned about the possible environmental effects of CFCs in 1972, when they were first detected in the atmosphere. We became active participants in an international industry group that had been organized to conduct a research program on the fate of these compounds in the environment. That group is now known as the Fluorocarbon Program Panel, operating within the administrative framework of the Chemical Manufacturers Association. Over the years, Kaiser Chemicals has conducted in-house research on possible replacements for current CFC compounds. We have also testified and extensively cooperated with federal, state and local agencies concerned with CFCs.

Press reports have stated that there was an agreement in principal reached in last month's Geneva negotiations to freeze world-wide CFC production to 1986 levels in 1990 and to cut production by 20 percent by 1992. We have not received a detailed report on the specifics of that agreement. We are concerned about any cutback in production. However, we strongly believe that if CFC production and use are to be regulated, such regulation must occur under a world-wide agreement rather than through unilateral action by the U.S. government.

We have sufficient confidence in current modeling work to state our belief that no significant changes in total ozone should be expected over the next few decades, so long as CFC emissions remain at or near existing levels. We also accept the modeling projection that significant increases in CFC emissions (say 3 to 5 times current levels) may, under some conditions, lead to appreciable ozone depletion during the next century.

Emphasizing our recognition and acceptance of the impact of this ozone depletion problem and averring our support of actions to alleviate adverse effects, we respectfully urge that the Subcommittees consider the following factors, in determining their immediate future action.

- No unilateral domestic action should be undertaken until all possibilities for uniform and concerted world-wide action have been thoroughly and exhaustively explored.
- In any legislation, CFC 22 should be considered "part of the solution" rather than "part of the problem."
- Future actions should be tempered by the knowledge that restrictive legislation can have unforeseen and unexpected consequences.

There is time to continue pursuing concerted world-wide actions. The sum total of our present knowledge does not support a finding of imminent threat to stratospheric ozone so long as CFC emissions remain at or near present levels. We sincerely believe that unilateral action with respect to CFCs, in repetition of the aerosol ban experience, would greatly reduce the chances of world-wide accord and would result in, at best, a short-term reduction in buildup of atmospheric CFC levels.

One cannot assume that "safe" substitutes will necessarily be employed. For instance, ammonia (a toxic substance) and propane (a flammable substance) are today in limited commercial use as refrigerants. Should development of safe substitutes for present CFCs be delayed or should the cost of these substitutes prove to be inordinately expensive, the use of less safe substances such as ammonia, sulfur dioxide or propane could return to the prevalence in existence 50 years ago, before the development of CFCs.

Import restrictions designed to control or prevent competitive advantages to non-participating foreign countries could be virtually impossible to administer and could have unanticipated and undesirable effects. This could occur, for example, for products in which CFCs could be employed at some step in a manufacturing process, but do not remain as part of the finished product. Would all such products be banned from importation into the U.S.? How would you verify foreign manufacturing processes? How would you treat components (such as foam) of products like autos? Would U.S. companies be precluded from participating in the world market for any products using CFC's in the manufacturing process?

The following additional information is in response to the questions contained in your letter of May 4, 1987.

Kaiser Chemicals produces three CFCs - K11, K12 and K22.

These products are produced at Gramercy, Louisiana, and represent more than 10 percent of Kaiser Chemicals' sales. The products are sold to the refrigeration/air conditioning, foam insulation, and packaging industries.

CFCs play an important role in our society. They are important to us and to our customers. We appreciate the efforts of this Committee to find practical, effective means of preventing any harmful effects of these products on our environment. We have the same goal. We believe it can be attained in a reasoned, constructive manner, with minimum disruption of our economy. Our opinion is based on these considerations:

* At current production levels, CFCs pose no long-term hazards. Atmospheric modeling calculations indicate that if world-wide production of CFCs 11 and 12 continues at the present rate, steady-state ozone depletion will be insignificant and greenhouse effects will be very small.

* There is no reliable evidence that CFCs have caused any decline in global ozone, which is as predicted by modeling calculations.

* Even if CFC production rises, there will be adequate time to validate models and develop replacements during the next two decades.

* Potential replacements for CFC 11 and 12 have been identified. They include CFC 22, which is commercial and can be substituted for CFC 11 and 12 in some applications, albeit at a cost penalty.

* The other most promising candidates appear to be CFC 123

and FC 134a. Neither is commercial, and all available information indicates that both will be produced with greater difficulty and at a much greater cost that CFC 11 and 12. Although preliminary toxicity tests have reportedly been encouraging, long-term inhalation test results are not available.

While FC 134a is free of chlorine and thus will not introduce chlorine into the stratosphere, CFC 123 will, probably to a similar extent as CFC 22. In the troposhere, the principal removal mechanism for FC 123 and FC 134a is expected to be reaction with hydroxyl radicals. Whether the compounds will react with other oxidants, such as those found in photochemical smog, to form harmful products is unknown.

Both compounds are expected to contribute weakly to the greenhouse effect. Preliminary tests by users indicate that FC 134a will function similarly to CFC 12 as refrigerant. FCF 123, on the other hand, is reportedly less efficient than CFC 11 in rigid insulating foams.

No listing of potential replacements is complete without inclusion of those commercially available, though toxic and/or flammable materials such as ammonia, sulfur dioxide and propane. These substances, in use before the invention of CFCs, and in limited commercial use even today have acceptable thermodynamic properties and are inexpensive compared to the CFCs now in use. Obviously, I am not recommending these substances as substitutes. However, we must recognize that if we regulate production of CFCs and do not regulate all of the substitutes, we may encourage production of substances which are toxic, flammable, or have other objectionable characteristics.

When considering chemical substitutes, both manufacturers and users must deal with present realities and future uncertainties.

CFCs 11, 12 and 22 are closely related molecules, which, under present technology, are manufactured in common or similar equipment, with attendant economics of scale and simplicity. Their original usage as refrigerants has broadened to a diversity of applications such as rigid foams, flexible foams, polymer building blocks, aerosols and specialty solvents.

CFC 22 is a commercially proven and safe hydrogen-containing molecule with decomposition characteristics that make for an ozone depletion potential 1/20 that of CFCs 11 and 12. Accordingly, we submit that CFC 22 should be considered as a substitute, and not as a candidate for production restrictions.

Substitutes now under consideration are more complex chemical compounds than CFCs 11, 12 and 22. This causes additional uncertainty with respect to yields, unwanted by-products and unexpected complications in manufacture and/or usage.

Both manufacturer and user face the risk that a given substitute, after conclusion of a lengthy and expensive commercial development effort, may be found objectionable from a toxological, environmental or other standpoint.

At present, we are holding technical discussions with specific customers with respect to potential substitutes for specific applications. So far, we have supplied no samples of substitute materials prepared in our own laboratories.

We are unable to respond to your questions with respect to prices and quantity of product demand required to bring substitutes into production or as to CFC prices expected to result from 20%, 40%, 50% and 95% reductions in production levels. CFCs, their precursors, and their derivatives are bought and sold in a complex and competitive world-wide market. We expect that CFC prices will continue to be market driven. However, we are unable and unwilling to speculate as to specifics.

We are concerned that any restrictions on international trade in CFC related products which would be imposed unilaterally by the U.S. government will result in economic sacrifices being borne solely or disproportionately by U.S. industry, workers, and consumers. Regulation of CFC related products is complicated by the fact that such products are so varied and fall into three very different categories.

- Direct Products - These are the actual CFC products such as CFC 11 and 12.
- Contained Products - This would apply to products such as certain foams, foam formulations, or other CFC containing mixtures.
- Derived Products - This refers to products such as certain foams, or circuit boards where CFCs were employed in the manufacturing process, but do not appear in the finished product.

For each category, the level of the economic burden borne by U.S. industry and workers will be determined by the extent to which any international regulatory program would affect the production activity of non-participating as will as participating countries.

In view of those considerations presented herein, our recommendations to Congress and EPA are as follows:

1. Encourage a continuing international program of research and monitoring to validate the predictive power of atmospheric models, and ensure that the long-range effects of CFCs are thoroughly understood.

2. Working with the Department of State through UNEP, develop an equitable program for controlling future production growth globally.

3. Provide positive incentives for the development of replacement compounds. If a global production cap is instituted and demand continues to grow, rising prices will provide adequate incentives for users to improve conservation methods and adapt them to the use of existing hydrogen-containing CFCs such as CFC 22 and for producers to develop replacements.

4. Direct EPA to formulate environmental impact standards for replacement compounds and to establish procedures for clearance before sizable quantities of such new products are released to the atmosphere. These standards should clearly state what, if any environmental effects may not be exceeded. It would be unfortunate if it were concluded that the minor ozone depletion or greenhouse warming, or the minute contribution to fluoride-containing acid rain by these compounds may pose a quantifiable and therefore unacceptable risk after producers and users devote major resources to the production and use of replacements.

We strongly urge against regulations leading to a phaseout of currently used CFCs. We respectfully submit that forced production cutbacks are not needed for environmental protection. If imposed globally merely to force producers to develop substitutes within a certain time frame, there will be penalties, and almost certainly, unforeseen and unexpected complications and side effects. Development costs will be unnecessarily high, and producers technically or financially unable to develop the needed processes and to construct new plants will be forced out of the business.

Unilateral U.S. production cutbacks in excess of those agreed to by all nations would be very detrimental. Since so many of our existing and potential export products incorporate CFCs or require their use in manufacture, such products will have to be manufactured with more costly replacements, and thus will become less competitive with products from unregulated countries. If other countries are not subject to similar restrictions as the U.S., CFC producers will have a powerful incentive to simply move their production abroad. The effect on U.S. employment as well as on our manufacturing base would be very detrimental.

In conclusion, we thank you for this opportunity to express our views on this subject. We are concerned about the environment, and we are working toward a timely, fair and workable solution to this significant environmental challenge facing the United States and the world.

TESTIMONY

OF

MARSHALL R. TURNER

VICE PRESIDENT OF MANUFACTURING

RACON INCORPORATED
(a subsidiary of ESSEX CHEMICAL CORPORATION)

BEFORE

THE U.S. SENATE COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS

MAY 13, 1987

Mr. Chairman and members of the Senate Committee on Environment and Public Works, I thank you for the opportunity to present Racon's position on the CFC/Ozone issue.

Racon's position is that the current bills before the House and Senate are too aggressive in their short time frames for phaseout. I think it prudent to cap production of R-11, 12 and 113 at current levels, but scientifically unjustified to include phase outs within 6-8 years with no compatible alternatives to implement now. I believe R-22 should be considered as part of the solution and not identified as part of the problem. It is easy to get carried away with the hype of the moment, but it will not harm the environment if a prudent course of action is adopted; One where a coordinated effort for control of releases and development of alternates between users and producers is encouraged.

Racon is a producer of chlorofluorocarbons 11, 12 and 22. We do not produce CFC 113, 114, 115; Halon 1211, 1301; carbon tetrachloride, methyl chloroform or methylene chloride. We do purchase some of the CFCs listed for resale. We do not use, handle or resell methyl chloroform or methylene chloride. We use carbon tetrachloride (purchased from others) as a feedstock to produce R-11 and R-12. 100% of Racon's yearly sales are in CFCs.

Racon provides CFCs to heating, ventilation, refrigeration and air conditioning wholesalers, original equipment manufacturers, insulation manufacturers, exempted aerosol packagers and producers of PTFE (polytetrafluoroethylene).

Chemical substitutes, besides R-22, most commonly known for refrigeration and air conditioning, are ammonia, ethylene, sulfur dioxide and natural gas. Racon produces R-22, but does not produce or supply any of the others. To my knowledge, there are no acceptable substitutes for foam insulation or chemical feedstocks for PTFE. Historically for refrigeration, ammonia, ethylene and SO_2 were the chemicals of choice (due to availability), but were displaced from the marketplace by CFCs. The main reasons for replacement were toxicity, workplace hazards associated with use and efficiency of application. Usage of these chemicals where the general public would be exposed could have the potential of a major, immediate catastrophe.

Racon's strength lies in our operational skills, personal service of customer needs and quick reaction to marketplace changes and requirements. We do not have as a Company goal to be a force in long term basic research for alternative development. Since 1964, these long term R&D activities have been left to those companies having the interest, expertise and staff size to perform.

Racon has not been just sitting back waiting for future events to unfold. Racon has been a member of the Fluorocarbon Program Panel of CMA since its inception, supporting the scientific investigation of the CFC/Ozone issue. We have developed a capability to produce additional R-22 if needed. As I said previously, I think R-22 can be a viable, near term alternative for substitution. Racon has developed a superior leak detector for closed system refrigerant and air conditioner applications and we continue to monitor developmental activities associated with the longer term alternates.

It is premature for me to speculate on what chemical substitutes may be available in the future. Those getting the most press include CFC 123 & 134a, but others here today are much closer to that development than I. To my knowledge, none of the alternates, other than CFC 22, are commercially available today, nor do they have a proven production route or demonstrated acceptable toxicity. To develop other than ballpark estimates given these circumstances is highly speculative at best.

Racon's main market niche, because of timing of entry, is supplying refrigerants to wholesalers who then service the aftermarket. While definitely involved with the safety and use of our products, our channel of distribution has shielded us from much exchange of information on alternatives with the end users of our products. We coordinate efforts in trying to provide the products and services to satisfy the needs as relayed to us through the other channel members. Racon is making presentations or providing information on the issues to various groups who request such assistance.

Surely if production is capped and a use allocation method is not mandated, prices for current CFCs will rise to the level necessary to supply the demand of the least cost sensitive user. Assuming that alternatives are available at equivalent cost, the price demand for the various applications will equilibrate. If alternatives are not available or if they are not cost justified, businesses will close and jobs will be lost. I cannot speculate on what those prices for either current CFCs or alternates may be.

Aggressive unilateral action by the U.S. seems extremely shortsighted to me. Threatening gestures by the U.S. appears to be counterproductive to meaningful international negotiations. The accused chemicals are efficient in their applications and relatively safe in the workplace, and if CFCs do affect ozone, the solution is international in scope, unilateral action will have little or no impact on the ultimate effect.

The implementation of plans to control CFCs will definitely have an impact on lifestyles. If the very short time frames proposed are implemented without acceptable alternatives, there could be major disruptions, but I am sure you will hear considerably more about this subject tomorrow from the experts -- the users of these chemicals.

Testimony of Harry C. Mandell, Jr., Ph.D.
Senior Vice President, Pennwalt Corporation

Presented Before

United States Senate

Committee on Environment and Public Works
Subcommittee on Hazardous Wastes and Toxic Substances
and
Subcommittee on Environmental Protection

May 13, 1987

PENNWALT
CORPORATION
CHEMICALS • EQUIPMENT • HEALTH PRODUCTS
PENNWALT BUILDING, THREE PARKWAY, PHILADELPHIA, PENNSYLVANIA 19102

Mr. Chairman,

I am Doctor Harry C. Mandell, Jr., Senior Vice President, Pennwalt Corporation. Pennwalt is a publically-held corporation headquartered in Philadelphia, Pennsylvania.

I am pleased to have this opportunity to present to this committee a report on Pennwalt's involvement in the chlorofluorocarbon industry and to tell you of our work on the development of alternative products.

WRITER'S DIRECT DIAL NUMBER: (215) 587-

Pennwalt is a manufacturer of CFCs 11, 12, 22 and 142b having a market share of between 8 and 10% of the total CFC production in the United States. Pennwalt does not produce CFCs 113, 114, 115, Halon or chlorinated solvents. Pennwalt's products are sold under the brand name, Isotron, and they are used for air conditioning and refrigerants, as propellants in specialty aerosols, as blowing agents for plastic thermal insulation foams, for packaging and comfort cushioning, and as precursors in the production of fluorinated elastomers and KYNAR resin, another Pennwalt product.

Pennwalt is very concerned about the ozone issue and is an active member of the Alliance for a Responsible CFC Policy. The Alliance, a group of some 500 concerned producers and users of CFCs is dedicated to protecting the stratosphere through steps that are scientifically and economically prudent.

We also actively participate in, and support the work of, the Fluorocarbon Program Panel of the Chemical Manufacturers Association. Formed in 1972, the panel consists of an international group of scientists representing 19 CFC producing companies from 10 countries, including Australia, Canada, most European countries, Japan and the United States. The panel funds independent scientific research aimed at improving the understanding of today's atmosphere, with emphasis on explaining the Antarctic ozone phenomenon and on the development of a network of ground-based monitoring stations for the detection of stratospheric change.

Pennwalt's policy regarding the CFC/ozone depletion issue is as follows.

First, we support the premise that there can be only a global solution to the problem. We are participating in the United Nations Environmental Program which has been meeting to develop a world-wide agreement on the production level of CFCs. Pennwalt's management has attended sessions of the UNEP as part of the International Chamber of Commerce delegation.

Second, we are opposed to any unilateral activity on the part of the United States that would reduce domestic CFC production. We believe that such an action would not provide a long term solution to a problem that is clearly world-wide in scope and, in addition, would damage the competitiveness of United States companies in many industries.

For example, Pennwalt Corporation owns and operates the only fluorspar mine in the United States. 80% of its production is converted by Pennwalt to hydrofluoric acid which, in turn, is used to produce Isotron products. The other 20% of the fluorspar is sold directly or indirectly to other critical industries such as optical glass, welding fluxes, aluminum and stainless steel manufacturing. A major contraction in demand for fluorspar might render the mine uneconomical. Pennwalt would become reliant upon imported fluorspar as are other producers of fluorocarbons. Thus again the United States would find itself required to import a raw material critical to several industries.

Third, Pennwalt joins with other members of the Alliance in calling for a global cap on CFC production at 1986 levels. Pennwalt believes that such a global cap would constitute an appropriate and immediate action pending continuing further scientific study of the stratosphere. We believe this testing must continue and any decision to modify the cap must be based on the results of this on-going research.

There also is, of course, the possibility of solving the problem through the development of replacement products. There are two types of CFCs: partially halogenated and fully halogenated ones. Fully halogenated CFCs are the type suspected of depleting the ozone layer. Partially halogenated CFCs are less stable and thought not to reach the ozone layer in harmful amounts.

CFC 22, an important part of Pennwalt's current product line, is not fully halogenated, has a relatively low potential impact on ozone and, therefore, should not be included in any restrictions that ultimately may be imposed. For example, CFC 22 is acknowledged to have only 5% of the ozone depletion potential of 11 or 12. Therefore, every substitution of 22 for 11 accomplishes at once an effective 95% reduction in potential ozone damage. Another Pennwalt product, CFC 142b is even less potentially ozone damaging than 22.

A blend of 22 and 142b was developed as a substitute for CFC 12 for the aerosol market in 1978. Toxicity testing, which was started in 1979, was not completed until August of 1983 and during that period of time, the propellant industry modified its equipment to use flammable, but low cost hydrocarbons as a substitute to CFC 12. Toxicity studies on 142b were acceptable and Pennwalt has marketed this product, and the 60%/40% 142b/22 blend, to the aerosol industry since 1984. This 60%/40% blend could also be a viable substitute for many cooling and refrigeration applications currently using CFC 12. Although the 60%/40% blend is considered nonflammable, pure 142b is rated as moderately flammable and this has caused concern with some end users. A word of explanation is necessary on the point of flammability. Pure 142b is rated by industry standards "moderately flammable". Blended with 40% of CFC 22, the mixture is not flammable. If, however, there were a slow leak that permitted 22 to leak out faster than 142b, the remaining mixture would become more concentrated in 142b and eventually even become flammable. Even though this is unlikely, we presently are working on what seems to be an acceptable technical solution.

Pennwalt has had discussions or sent samples of 142b and blends of 142b/22 to customers in the automotive, polystyrene, and CFC 12 appliance industry. The anticipated selling price of the 60/40 142b/22 blend is $1.50/lb.

assuming high levels of production. Our present CFC 12 price is $.60. Pennwalt's present capacity for 142b is limited and is equivalent at present to 10% of the U.S. 1986 production of CFC 12. A new 142b plant would take approximately three years to build at a cost of approximately $30-50 million. In addition, Pennwalt could conceivably convert its manufacturing capabilities for other CFCs to 142b.

Because we believe we have a substitute for CFC 12 now commercially available, Pennwalt has spent proportionately more of its R&D budget on 142b and proportionately less on other CFC substitutes.

Replacement of CFC 11 for the rigid and flexible polyurethane industry has proven difficult. CFC 11 is not only an excellent blowing agent but major customers have indicated that a comparable blowing agent costing more than $1.25/lb. would render them non-competitive with other forms of insulation. Pennwalt is currently working with 141b as a substitute for CFC 11. We should have sample material ready by third quarter 1987. Samples have been requested by all of our major customers in the foamed plastics industry. Although 141b can be commercially produced with some plant modifications, it, too, has drawbacks. It is moderately flammable and it is unproven that it blows acceptable foam. It may cost more than the desired $1.25/lb and once again, current capacity could not satisfy industry requirements. In addition, a toxicity study of at least three years would have to be performed on 141b before it could be sold.

SUMMARY

We think it important to emphasize that the American chemical industry has effectively and economically effected transitions from the use of substances which have been identified as dangerous or deleterious such as leaded gas, asbestos and DDT. It is seldom possible to find replacement materials which are identical in all respects. It is scientifically reasonable to expect that there will be different costs, different handling and application variables, different physical and chemical properties, but under our free enterprise system producers and consumers have made cost effective transitions from more harmful to less harmful materials and the same can be done with chlorofluorocarbons.

What industry needs is a reasonable period of time and a reasonable opportunity to effect economically and technically viable changes. What we do not need or want is a sudden and unilateral imposition of punitive restrictions which have a substantial economic impact, which injure us economically vs our global competitors and which impair our incentive and ability to develop useful alternatives.

ALLIANCE FOR RESPONSIBLE CFC POLICY
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Statement

of

Richard Barnett

Chairman

Alliance For Responsible CFC Policy

U.S. Senate Environment and Public Works Committee
Subcommittee on Hazardous Wastes and Toxic Substances
Subcommittee on Environmental Protection

May 13, 1987

Good morning Mr. Chairman, Committee Members.

I am Richard Barnett, Chairman of the Alliance For Responsible CFC Policy, and I am also Vice President and General Manager of York International, in York, Pennsylvania, a manufacturer of commercial, applied and residential air conditioning equipment.

On behalf of the members of the Alliance, I would like to thank you for the opportunity to appear before your subcommittee today to discuss issues concerning ozone depletion and the relationships between domestic and international efforts to arrive at an effective resolution of concerns for depletion of the earth's ozone layer and the need for development of compounds to take the place of current chemical compounds such as the fully-halogenated chlorofluorocarbons (CFCs).

As you know, in September of 1986, the Alliance issued a policy statement outlining seven points necessary for an effective and responsible policy with regard to CFCs. The statement was based on our assessment that the current use and emission of CFCs presented no known threat to health and the environment, but that uncontrolled growth in the use and emissions of these compounds should not be encouraged absent better scientific understanding.

NOTE: The attachments to this statement have been retained in committee files.

The Alliance's policy statement then outlined the steps necessary to address the ozone depletion issue from the public policy perspective, namely:

- -- the negotiation of an international agreement on fully-halogenated CFC production capacity;
- -- research and development of CFC emission control technologies and processes;
- -- research and development of alternatives to the fully-halogenated compounds;
- -- avoidance of unilateral regulatory programs in the United States; and
- -- continued aggressive assessment of this complex scientific issue.

The Alliance continues to believe that this policy is sensible from the perspective of both environmental protection and potential economic impact of the U.S. economy. You will note in the Alliance's attached statement given at the most recent UNEP negotiating session, that the Alliance has also stated it will accept an emissions freeze at or near current levels for the fully-halogenated compounds so long as the international agreement provides for periodic scientific, economic, and technological review. The policy outlined we believe will most efficiently bring about the development of substitute compounds.

In your letter of request for testimony, you have raised several points and questions concerning these issues and their relation to the eventual development of substitutes for the current CFC compounds. The comments below and attached materials are provided in response to these points.

First, with regard to the status of the international negotiations, I feel it necessary to reiterate our view that the international agreement is the only means of developing an environmentally effective program without placing U.S. industries at a further competitive disadvantage. Domestic industries are already disadvantaged in the current negotiations. An emissions freeze would be much less burdensome to European and Japanese industries since the U.S. unilaterally acted to control aerosol uses of CFCs without gaining similar actions worldwide. Aerosol uses continue to be the single largest use of CFCs outside the United States.

A quick review of recent U.S. import and export data reveals that as much as 2/3 of U.S. trade imports and exports may use or rely on CFCs in one way or another. A unilateral program, with or without trade restrictions, that imposes greater costs on U.S. industries will place our industries at an international competitive disadvantage. If air conditioning, which currently accounts for more than $1 billion in exports, becomes less energy efficient because of a unilateral regulatory measure, then demand for those products is likely to fall.

The government's efforts in this area should be to reach an effective international agreement that minimizes the costs to our economy but also promotes the development of substitute compounds. Attached to this testimony is an outline of what factors we consider to be important in this negotiation process.

Second, we believe that an effective international agreement that freezes emissions of the fully-halogenated compounds, accompanied by periodic scientific, economic and technological review, is an adequate policy to protect the environment and to spur development of substitute compounds. Our analysis indicates that a weighted production freeze on CFCs 11, 12, and 113 at 1986 levels would cost the economy approximately $1 billion during the period 1988-2000, primarily due to increases in CFC prices. Annual costs would exceed $180 million in the mid-1990's.

Based on our analysis, CFC prices will rise immediately, more than doubling in price in the first year of a production freeze. In the mid-1990s, CFC prices are estimated to be three to four times higher than current levels but will be expected to moderate in the late 1990s as new CFC substitutes become available. As a result of higher prices, new substitutes would be developed and new CFC capture and recycle technology would be applied by industry. The CFC price increases we anticipate will be a powerful market incentive and will make CFC substitutes competitive with current CFCs.

Also, the freeze is expected to curtail 1.1 million metric tons of projected CFC use by the year 2000, or the equivalent of 4 years production at current U.S. production rates.

This substantial unmet market will provide a significant stimulus for the development of substitute CFCs or other alternative compounds.

It should also be noted that a freeze at 1986 levels will actually be a reduction step if current world growth patterns are followed and implementation occurs between 1988 and 1990.

With regard to proposals in Senate bills S. 570 and S. 571 to initiate a 95 percent production rollback, it is impossible to place precise cost estimates on the impact of such a measure but the cost would be enormous. Currently 37 percent of CFC -11 and -12 production is used to service installed equipment. If CFCs are not available, capitol stocks of installed equipment would become prematurely obsolete for many consumers and CFC-user firms.

As an example, fully-halogenated compounds are currently used to operate 100 million home refrigerators and 91 million auto air conditioners. A 95% rollback by 1993, as required in S. 571, could render approximately 18 million auto air conditioners valued at more than $6 billion useless in 1993. In subsequent years similar costs might be incurred.

Such a draconian measure as that contemplated by the Senate bills could actually bring on these undesireable impacts more quickly than the schedule contemplates as CFC producers lose economies of scale to operate their facilities and decide to leave the business entirely.

The massive consumer dissatisfaction with the effects of such a program and economic costs to society could threaten the viability of our ozone protection efforts.

Third, efforts internationally or domestically, to require short-term reduction steps are ill-advised. Although many CFC user industries are currently examining what can be done to reduce emissions in the short-term, it is not possible for the affected industries to produce estimates of what is achievable or what the potential economic impact of such CFC reduction requirements may be.

Reduction measures, particularly in the U.S. where we have unilaterally eliminated aerosol uses, that occur prior to the commercial availability of acceptable substitute compounds could lead user industries to choose currently available, but less desirable alternatives that are either more toxic, are carcinogenic, flammable, or less energy-efficient than the CFCs being used today. Premature reduction steps could actually increase risks to workers and consumers, increase energy consumption, and ultimately reduce the market demand for the much discussed but as yet unavailable CFC substitue compounds.

Industries that shift to currently available, but less desirable, substances are not likely to be interested in shifting again to the new compounds and thereby incurring redesign costs twice. Further, neither the Environmental Protection Agency nor anyone else has done analysis of the environmental or economic impact of adopting such restrictions. The Alliance believes it is unwise and unnecessary to negotiate any reduction measures as part of the current international negotiations. Such measures should be considered as part of the periodic assessment process we have advocated in the international agreement.

Fourth, both the international and domestic ozone protection efforts should focus only on the fully-halogenated compounds (CFCs 11,12,113,114, and 115) and the halons. Other compounds, such as CFC-22, that have little or no ozone depletion potential should be considered part of the solution and not part of the problem.

The international agreement should incorporate a management process that allows for the consideration and inclusion of additional compounds as is deemed necessary scientifically.

Finally, let me again emphasize that the international agreement is the only means of developing a program that is environmentally effective and minimizes economic disadvantages to U.S. industries. The international agreement should include effective trade restrictions for bulk chemicals and products containing

CFCs from non-signatory nations. Trade restrictions must be designed so they can protect domestic manufacturers by effective and vigorous enforcements of these restrictions.

In our view, a unilateral CFC program in the United States that attempts to govern the world economy through trade sanctions will only serve to further isolate U.S. industries in the world market. Such an effort should be discouraged.

The focus of the U.S. government's efforts should be to achieve a simple, fair, effective and enforceable international agreement with broad participation among the world community. The U.S. ozone protection program should be consistent with and no more stringent than the international agreement. It is in this manner that U.S. technological know how will provide for protection of our environment and ensure that we remain competitive in the world marketplace at the same time.

Thank you, I will be happy to answer any questions you may have.

STATEMENT OF DAVID D. DONIGER
SENIOR ATTORNEY, NATURAL RESOURCES DEFENSE COUNCIL
ON BEHALF OF THE NATIONAL CLEAN AIR COALITION

HEARINGS ON PROTECTION OF THE OZONE LAYER
SUBCOMMITTEE ON ENVIRONMENT
SUBCOMMITTEE ON HAZARDOUS WASTE AND TOXIC SUBSTANCES
SENATE COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
MAY 13, 1987

Thank you for the opportunity to testify for the Natural Resources Defense Council on the threat to the ozone layer and global climate from chlorofluorocarbons (CFCs) and related chemicals. I am also speaking for the National Clean Air Coalition, composed of more than two dozen health, environmental, civic, labor, and religious organizations, which supports the rapid phase-out of these chemicals.

In testimony before these subcommittees in January, I summarized the dangers from CFCs and halons and explained why a rapid, virtually complete phase-out of emissions of these chemicals is essential to protect public health and the environment world-wide. For that reason, we support the U.S. position, developed last fall by the Environmental Protection Agency and the State Department and twice cleared by the Administration as official government policy, to phase down four CFCs and two halons by 95% in 10-14 years. NRDC and the NCAC also commend Senators Baucus and Chafee and their cosponsors for introducing S. 570 and S. 571 which, along with H.R. 2036 in the House, would accomplish the 95% phase-down of these pollutants even more expeditiously.

I propcse to concentrate my testimony today on disturbing recent events in the international negotiations and domestic policy making on CFCs, and on the steps that must be taken to rectify the situation in the coming weeks and months. Let me begin, however, by setting forth the scientific benchmark against which we believe success or failure must be measured.

Yesterday, you heard compelling scientific testimony that only underlines the need to implement the 95% phase-down. To us, the most important conclusion from that testimony and previous scientific analysis is that the atmospheric system is drastically out of balance for CFCs and related compounds. Current CFC and halon emission rates so greatly exceed natural means of removal that an 85% cut in emissions is needed just to stabilize their atmospheric concentrations, let alone cleanse them from the atmosphere. Any lesser reductions will allow the atmospheric stockpile of these long-lived chemicals -- a stockpile apparently already high enough to cause the Antarctic ozone hole and other disturbances in the ozone layer -- to keep building higher each year.

We should all remember that the 95% phase-down policy was developed on the basis of a broad scientific analysis, but without taking into account such phenomena as the massive and unexpected Antarctic ozone hole. As Ambassador Richard Benedick stated at a CFC conference on March 25, "we have simply excluded that disturbing phenomenon from our equations." Now, however, scientists from the National Ozone Expedition who have directly investigated the causes of the Antarctic hole have testified that it is probably linked to CFCs. While many scientific issues remain to be explored, these developments reinforce the inevitability of the 95% phase-down policy for policy makers with any sense of prudence in the face of potentially catastrophic global consequences.

A second benchmark for policy alternatives is whether they would provide the necessary incentives for the rapid development and deployment of safe substitute chemicals to replace the conventional CFCs. Economic analyses by three sources -- the EPA, the World Resources Institute, and the Environmental Defense Fund -- all point in the same direction: That reductions of 50% or more are needed to assure immediate and accelerated development and deployment of those substitutes. Under a 20% reduction program, serious progress on substitutes is unlikely for years. But we must be clear that a 50% reduction is not enough to protect public health and the environment. The availability of substitutes would not by itself push the other 50% of conventional CFCs out of the market. Rather, since they probably will be less expensive than the substitutes, they would likely remain in use indefinitely. That is why control requirements must accomplish the full 95% phase-down.

With this background I turn to recent international and domestic events. Early press reports on the meeting in Geneva at the end of April conveyed a highly misleading impression that an agreement to protect the ozone layer had been reached. This misimpression must be corrected, for in reality the parties are still far from any agreement and farther still from an effective one. In fact, the document that resulted from the Geneva session contains several alternative, mutually exclusive proposals covering only some of the pollutants of concern. The most lenient alternative would achieve only a 20% reduction and would be an environmental disaster. Even the most stringent option in the document would tentatively assure only a 50% reduction in only the CFCs (not the halons) by the late 1990s -- less than 50% if any allowance is made for growth in developing countries. This is far less than the 85% reduction needed just to stabilize CFC and halon concentrations in the atmosphere. Agreement on reductions that would stabilize and eventually reduce the atmospheric stockpile would remain only a hope for the future.

Let's examine the document more closely. First, the parties have yet to agree on what chemicals should be covered. The document covers five CFCs but not the two fastest-growing compounds, the halons. At least one country (Japan) has reserved agreement to coverage even this broad and apparently still hopes to keep CFC-113, whose use is growing very rapidly, out of the agreement. There is some feeling among participants returning from Geneva that CFC-113 and the halons ultimately will be included if the U.S. and others continue to press for it. The U.S. must make sure UNEP's Governing Council expands the mandate of the negotiations to cover the halons, a modification Dr. Mostafa Tolba, UNEP's Executive Director, has pledged to seek.

As for levels of reduction, the only option which commands unanimous support is a freeze on CFC emissions by about 1990 and a 20% reduction by 1992. Under consideration but not agreed to are two alternatives for an additional 30% cut:

- a "positive trigger" which would bring total reductions to 50% by 1994 only if a majority of the parties to the protocol consent at some time in the early 1990s, or
- a "negative trigger" which would bring total reductions to 50% by 1996 unless two-thirds of the parties dissent at some time in the early 1990s.

The "positive trigger" option is clearly worth very little, depending as it does on future majority votes for going beyond 20% reductions. Moreover, all these dates could all slip if ratification of the agreement by the necessary number of nations is delayed.

Even under the "negative trigger" option, reductions beyond 50% would have to be agreed to at an undetermined time in the future. Here also there are two alternatives: a requirement for agreement by a majority, or by two-thirds, of the parties.

Also endangered in Geneva were trade incentives in the U.S. position that would prohibit signatory nations from accepting imports of products containing CFCs from countries that do not have requirements at least as stringent as those in the treaty. These provisions are crucial because they are the principal means for assuring compliance by reluctant nations. In previous sessions, the parties appeared to have agreed to U.S. proposals to control trade in bulk CFCs and in products that contain CFCs; provisions to control trade in products made with CFCs but no longer containing them (e.g., computers) were under study. In Geneva, however, all trade controls were downgraded to the level of study.

There will be some who say that important progress was made in Geneva, and that the European Community and Japan are moving. I will not deny that there has been some movement, but the pace has been truly glacial and distance travelled is minimal in view of the objective of stabilizing and reducing the atmospheric stockpile of CFCs. There was, in fact, one very substantial breakthrough. As the result of prior U.S. leadership, West Germany broke from the rigid position dictated by other EC countries, notably Britain and France, to advocate major reductions, possibly even a total phase-out. Austria and Switzerland (not members of the EC) also announced unilateral reduction decisions already being implemented. But the EC as a whole and Japan have not yet subscribed to any proposal that goes beyond 20% reductions.

Clearly, all the hard bargaining lies ahead. That in itself is not so bad, if the U.S. remains committed to obtaining the necessary result. EPA Administrator Lee Thomas and his staff deserve great credit for formulating the U.S. 95% phase-down policy, and for pursuing it in cooperation with Ambassador Richard Benedick and other State Department officials. The month of April, however, saw an attempt to sabotage the established U.S. policy by a faction of junior and middle level officials in the Office of Management and Budget, the White House Office of

Policy Development, the Departments of Interior and Commerce, and several other agencies. The conduct of these officials, and the conduct of their representatives on the U.S. delegation in Geneva, have raised serious questions about the ability of the State Department and EPA to advocate and secure agreement on the official U.S. government policy. These questions must be swiftly resolved.

Throughout the month of April, a group of as many as 30 people from these and other agencies met repeatedly on every detail of the CFC issue. While some agencies (e.g., the Council of Economic Advisors and the U.S. Trade Representative) appeared to be supportive of the established U.S. policy, staff from the departments and agencies named above conducted a hostile grilling of EPA staff. They started and finished the series of meetings by hearing from industry officials; environmental representatives were given one audience near the end of their deliberations. From my own observation and other reports, these officials exhibited a strong presumption against the seriousness of the danger of ozone depletion and the seriousness of the health and environmental hazards from it. One OMB official in fact suggested that skin cancer should be regarded as a "voluntary" consequence of sun exposure, and thus might be ignored in governmental decisionmaking. (I am attaching the thoughtful response of Dr. Margaret Kripke, the chairman of the ozone depletion subcommittee of EPA's Science Advisory Board, on this issue.) Simple errors of noncontroversial science were evident even as late in the game as our audience with this group.

The apparent goal of this faction was to hold the U.S. negotiating team in Geneva to advocating no more than a freeze, or perhaps a 20% reduction, in CFCs. EPA, State, and several other agencies strongly defended the phase-down, however, and in the end no change was made in the official position.

Two members of this faction, however, were appointed to the U.S. delegation, one from the Department of the Interior and one from the National Oceanic and Atmospheric Administration in the Commerce Department. In Geneva they continued efforts to undercut the State Department and EPA throughout the week of negotiations. They persistently challenged Ambassador Benedick's authority to make statements that in fact conformed to the established U.S. position.

While Benedick and EPA representatives appear generally to have maintained control over the situation, the NOAA and Interior representatives clearly created problems. For example, a draft document from earlier in the week lacked even the "negative trigger" approach to the second-stage 30% cut, leaving it completely dependent on future actions. Hampered by the NOAA and Interior representatives, the U.S. negotiators left it to other countries to propose the "negative trigger." In contrast to the U.S. team's forceful advocacy in Vienna in February, there was little, if any, U.S. emphasis on securing reductions beyond 50% as specified in the official U.S. position.

We expect these same officials to make another run at the U.S. policy in a Domestic Policy Council meeting planned for later this month. Their goal now would seem to be rolling back the U.S. position to acceptance of a mere 20% cut, or perhaps at most to the "positive trigger" option for getting to 50%, which requires a second agreement later. It would be an international embarrassment for the U.S. if these efforts at sabotage within our own government are allowed to succeed. EPA Administrator Thomas, who deserves great credit for developing and pursuing the U.S. phase-down position to date, must repudiate their efforts and continue to push the established U.S. policy forward.

In our view, the U.S. must take whatever steps are necessary between now and July to secure three main improvements in the Geneva document in further negotiations:

- The agreement must include the two halons, the most potent and rapidly growing ozone depleters.
- The agreement must require reductions to the point of stabilizing the atmospheric system and eventually cleansing it, i.e., to 95%. This is especially necessary in view of testimony yesterday that the Antarctic ozone hole is probably being caused by CFCs.
- The agreement must have strong provisions to control trade in products containing or manufactured with CFCs, provisions which U.S. negotiators allowed to backslide in Geneva.

On these main points the Administrator must allow no compromise in the U.S. position and in the final product of the negotiations.

Let me now turn to the domestic rulemaking required under Section 157 of the Clean Air Act. Given the involvement of OMB and other agencies, that decision will also be hotly contested. On the basis of EPA's findings about the dangers of these compounds, Section 157 of the Clean Air Act directs Administrator Thomas to issue regulations curbing CFC and halon emissions in the U.S. In 1986 NRDC and EPA reached a consent agreement which established deadlines for decisions on domestic rules. Under the original agreement the date for proposing regulations fell due on May 1 of this year, and the date for final action on November 1. NRDC earnestly believed these deadlines allowed EPA the time it needed, and throughout the last year we pressed the Agency for timely and forceful domestic action. We were disappointed that such action has not yet been taken. EPA, however, has persuaded us to accept an extension of these dates in order to complete preparations for issuance of rules. On Monday of this week, NRDC and EPA jointly filed with the court a motion to extend the deadline to December 1, 1987, and August 1, 1988, respectively. (The Agency's explanation of the need for this time is attached to my testimony.) We anticipate agreeing to no further extensions.

NRDC and the NCAC believe that EPA should be using the extra time to develop an aggressive U.S. domestic regulatory proposal consistent with the U.S. proposal of 95% reductions for the international negotiations. To be effective, such a proposal for U.S. regulation would have to include restrictions on the import of CFC-derived goods into the U.S. from any country which has not adopted a phase-down policy at least equal to ours. The prospect of such a domestic program constructively increases the pressure on the international negotiations, for each other country must consider the possibility of adverse trade consequences failing to reduce CFCs and halons on the schedules provided under the U.S. domestic program. So far, however, EPA has at best only hinted at such a strategy. We call on Administrator Thomas to declare that strategy openly and pursue it aggressively.

There are those who counsel against proposing, or even suggesting, any domestic action until and unless an international agreement is signed. I believe that, wittingly or not, persons who take that position are giving away an important card the U.S. must play to be successful in the international negotiations, and in so doing they play into the hands of the British, the French, and the Japanese. If the U.S. uses the leverage in appropriate trade restrictions, it is difficult to see why any major CFC producer or user nation would choose to abandon lucrative U.S. markets for consumer and industrial goods rather than institute a domestic phase-down to parallel ours. If the U.S. uses that leverage, I believe it can achieve the agreement of other nations on the 95% phase-down.

While EPA and the Administration as a whole have the authority to take the necessary actions if they so choose, NRDC and the NCAC recommend that Congress rapidly enact legislation to accomplish the 95% phase-down. We have every right to demand that EPA and the State Department insist on a 95% phase-down agreement internationally and that EPA institute the 95% phase-down domestically. These subcommittees should press Administrator Thomas and other witnesses tomorrow for concrete commitments to do so. Nonetheless, recent events on CFCs and many disappointments in other areas teach us that we cannot safely rely on this Administration to protect public health and the environment. There must be a legislative guarantee. Consequently, we urge you to move rapidly forward in the coming months to enact legislation on the model of S. 570 and S. 571.

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Summary of Testimony by

Dr. Irving Mintzer

World Resources Institute

before the U.S. Senate

Environment and Public Works Committee

May 13, 1987

- Regardless of the cause of the Antarctic Ozone Hole, enough is known about ozone depletion worldwide to demand immediate action to regulate, reduce, and replace the most harmful CFCs.

- The Draft Protocol developed at the Geneva negotiating meeting is a positive and constructive compromise. It provides a workable and broadly attractive mechanism for international regulation of CFCs. Congress must remain vigilant and aggressive in pursuit of an adequate international agreement to insure that a strong protocol is accepted by all the signatories to the Vienna Convention.

- The industrial world has not only the responsibility to protect the earth's ozone layer from manmade chemicals, but also the capability to do it without economic and social disruption.

- CFC emissions can be cut by at least 50% within five years by actions that will perpetuate both a healthy global economy and a healthy ozone layer.

- To provide adequate economic incentives for the rapid introduction of safe alternative CFCs, the U.S. and other nations must be prepared to enact strong CFC control regulations. If such regulations cannot be agreed to internationally, the U.S. must be prepared to act unilaterally.

- Because American companies are capable of producing safe CFCs, they could lead the world to the next generation of chemicals. If we fail to meet the challenge of development in the U.S., we will be buying these chemicals from other countries in the future.

The policy implications of ozone depletion and the greenhouse effect are a major focus of the World Resources Institute, an independent policy research center concerned about global environment and resource issues. As Director of the Energy and Climate Program at WRI, I have been working on the linked issues of ozone depletion and global warming since 1983. In the last two years WRI has organized several briefings on the ozone depletion problem, including a two-day meeting in April 1986 attended by representatives of six European non-governmental organizations. Last November, WRI published "The Sky Is the Limit: Strategies for Protecting the Ozone Layer", authored by myself and Alan Miller. We evaluated the science and concluded that policies should be adopted now that (1) promote the more efficient use of CFCs, (2) stimulate the introduction of alternative, safer CFC-formulations and (3) encourage the development of technologies employing non-CFC substitutes. Specifically, we recommend the adoption of a $5 per pound tax on CFCs, weighted to reflect the difference in ozone-depletion potential of the various compounds. A tax of this magnitude, we believe, would spur introduction of safe CFCs and reduce emissions of CFC 11, 12, and 113 by 30 percent or more in the next five years. (See Table 1.) On the basis of information learned since the report was completed, we believe that our initial estimates were overly conservative and that emissions could be reduced at least 50 percent in five years. A copy of this report has been made available to the Committee.

I have also authored a study of the greenhouse problem, titled "A Matter of Degrees: The Potential to Limit the Greenhouse Effect", published by WRI in April 1987. CFCs are potent greenhouse gases, currently contributing about a third as much to global warming as carbon dioxide does but growing much more rapidly. My report examines the effects of policy choices made today on the rate of future emissions of CFCs and other greenhouse gases. It also analyzes the implications of these different rates of growth for global warming. One conclusion of this analysis is that actions taken in the next decade will have a significant effect on the timing and magnitude of future global warming and the associated climate changes. Policies to reduce the rate of greenhouse gas emissions can substantially slow the rate of climate change. Strategies to reduce emissions of CFCs are one important way to slow that build-up.

Last week I returned from the Geneva meetings sponsored by the United Nations Environment Programme (UNEP) for the purpose of negotiating a protocol to protect the ozone layer. I am also a member of a panel of the EPA Science Advisory Board created to review the agency's risk assessment of ozone depletion, the background document for its regulatory policy. I will address three topics in this testimony: the on-going efforts to reach an international protocol to limit CFC emissions; the current status of efforts to develop safer, alternative formulations of CFCs and non-CFC substitutes to replace the traditional CFC compounds; and the trade aspects of CFC regulatory policy. I will conclude with a discussion of policy opportunities and options.

Status of Efforts to Achieve an International Agreement

The Vienna Convention for the Protection of the Ozone Layer is an historic accomplishment in the evolution of international environmental cooperation. As adopted in 1985, the Convention creates a general obligation of the signatories to control activities that "have or are likely to have adverse effects" on the ozone layer. The Convention also created a process for continuing governmental dialogue on a protocol for restricting CFC emissions. Substantial progress has been made toward that goal at two international technical workshops held last May and September and at inter-governmental negotiating meetings in Geneva last December, in Vienna in February, and again during the last week of April in Geneva.

Under the able leadership of Dr. Mostafa Tolba, Executive Director of UNEP, this week of difficult and protracted negotiations bore fruit. Its achievement was the production of a draft protocol that is positive and constructive. This Conference Draft document could form the basis for a powerful agreement and set a lasting precedent for future international cooperative efforts to protect the environment.

Before outlining the details of the proposed draft protocol, it is important to note that the Conference Draft submitted for your review is not legally binding until approved in the capitals of the signatory states. For this reason, the next phase of the negotiations, which will occur over the next five months in dozens of capitals, is of crucial significance. We in the international community of non-governmental organizations look to the members of this Committee and to others in the Senate to fight vigorously to sustain this important compromise. Your role is absolutely critical to achieving our shared goals of protecting the environment, sustaining economic growth, and, in particular, of reducing the risks of ozone depletion.

Needless to say, the current Conference Draft is not a perfect solution to the problem of global ozone depletion. It does not completely eliminate the risks of future CFC buildup. It is a compromise proposal which covers only the most dangerous chemicals, reduces their production and use by 50 percent, and provides for periodic reviews of the science to determine the adequacy of the control strategy. This agreement would freeze production and imports at the 1986 levels of each of the fully halogenated CFCs (i.e., CFCs 11, 12, 113, and optionally 114, and 115) two years after entry into force of the protocol. Two years later, production and use of these compounds would be reduced automatically by 20 percent below the 1986 levels. Two options are currently under consideration for a second stage of reductions that would limit production and use of these compounds to an amount equal to only 50 percent of the 1986 levels. Option 'A' would impose these additional 30 percent reductions six years after the convention enters into force, pursuant to a positive majority vote of the parties. Option 'B' would impose the same percentage cuts automatically after eight rather than six years unless two-thirds of the parties voted against the scheduled reductions. The World Resources Institute strongly endorses Option 'B' calling for the automatic reductions unless the parties vote against it. Such a "negative trigger" approach is much less likely to overturn the proposed reduction schedule in future years. In addition to these scheduled reductions, the Conference Draft contains a further provision for future reductions beyond the 50 percent level if the science suggests the need for them and the parties agree.

The Conference Draft also includes two important provisions concerning future reviews of the scientific evidence on ozone depletion. The first provision mandates a major international re-assessment of the science every four years. The second allows for a subset of the parties to request an interim or emergency review should the science "sour" as new results emerge. This provision for emergency review is crucial to the creation of a flexible instrument, one capable of dealing prudently with the kind of sobering new evidence revealed in these hearings yesterday concerning the nature and causes of the Antarctic Ozone Hole.

To achieve the proposed compromise, each of the parties has made significant concessions in the last year. The official U.S. position on entering the negotiations had been to seek an immediate freeze on emissions of all the most harmful chemicals that threaten the ozone layer, coupled with a long-term commitment to phase out up to 95 percent of these emissions. A few other countries, notably Canada and the Scandinavian countries, have supported this U.S. position. The Scandinavians have proposed an additional, immediate twenty-five percent cut in emissions, and the Canadians have also advanced proposals that would require cuts in emissions by the large industrialized countries.

In the interest of reaching an international agreement, the U.S. has agreed to delete the Halons and the chlorinated solvents from the Conference Draft and to remove explicit mention of the 95 percent target for future reductions. These compromises do not significantly weaken the agreement because the Halons and the chlorinated solvents together contribute little to the current risk of ozone depletion. If their recent high growth rates (and their contribution to future ozone depletion) continues to grow rapidly, they can be included in the protocol at a later date. Dropping the explicit target of 95 percent reductions is no a problem if the commitment for 50 percent reductions and the provision for further possible reductions are observed faithfully. Risks will rise rapidly, however, if those who argue to limit reductions to levels that reduce emissions by less than 50 percent are allowed to undermine the current compromise.

The largest producers and users of CFCs outside the United States, i.e., the European Economic Community, the Soviet Union, and Japan, have in the past not been willing to go so far in efforts to control future emissions. They had previously offered only a freeze and 20 percent reduction on CFC 11 and CFC 12, the two chemicals that currently contribute the greatest amount to potential ozone depletion, with a commitment to re-evaluate the need for further regulation at some future date. Their major concessions last week in Geneva were to include CFC 113 in the protocol and to accept reductions beyond 20 percent.

The earlier EEC proposal was considerably less protective of the ozone layer than the U.S. proposal. The current EEC position does represent substantial progress from their earlier proposals. On the basis of my observations of the Geneva meetings, I am optimistic about the prospects for reaching an agreement this year based on the current compromise of the U.S. and EEC positions. It is important to note that the EC Council of Ministers has not yet approved this draft. They are scheduled to consider the issue at a special meeting on May 28. Those struggling to gain approval of this compromise in Europe have many difficult hurdles to surmount. Resistance by some of the chemical companies is stiff. Only with strong and continuing U.S. support, and, in particular, with the vigilant efforts of this Committee, will the more reasonable European governments be able to overcome this strong resistance.

The outcome of future negotiations will be affected by the results of on-going research to explain the Antarctic Ozone Hole; if scientists can demonstrate, as they suggested here yesterday, that CFCs are the principle cause of the Hole, this would have an important psychological impact on future negotiations (even if the phenomenon is unique to Antarctic conditions). Even without reference to this research, it was apparent at the Geneva meeting that all parties recognize the risks of stratospheric ozone depletion. There is a substantial common interest in obtaining an agreement. My personal judgment is that there is considerable willingness in the EEC to seek a strong and meaningful agreement; by the end of the meeting, representatives of several member nations were informally proposing positions that went considerably beyond the formal EEC position. West Germany, for example, broke publicly with the EEC by announcing its willingness to accept reductions of 50 percent from 1986 levels. The Federal Republic plans to accomplish such reductions domestically by banning the production of CFCs in aerosol applications later this year.

I am not, however, convinced that the draft agreement reached will be adequate by itself to protect the ozone layer. It appears likely that the agreement will not cover all ozone-modifying chemicals, ignoring the Halons, which are the fastest growing compounds in this group. An agreement of the sort proposed will help and is substantially better than where we are now, but is not by itself enough to solve the problem.

CFCs have atmospheric lifetimes of up to 100 years or more. As a consequence, constant emissions imply continued substantial growth in the atmospheric concentration of chlorine, which increases the risk of ozone depletion. An immediate cut of over

85 percent is necessary to keep atmospheric chlorine concentrations from rising still further. (See Figure 1.)

Continued growth in emission of some ozone-depleting substances implies that future policy action will have to much more severe to limit the risks of ozone depletion. Selecting some dangerous chemicals to regulate and ignoring others that make the problem worse could provide a false sense of lowered risk while committing the atmosphere to substantial future depletion.

Significantly reducing the risks of ozone depletion will require the phase out of the most harmful compounds and the rapid introduction of alternative, safer CFC formulations. The controls envisioned in the current draft proposal may not be adequate to stimulate the rapid introduction of substitutes. To provide adequate economic incentives for the rapid introduction of alternative, safe CFCs, the U.S. and other nations must be prepared to enact strong CFC regulations -- if necessary unilaterally.

The draft proposal described above is a complex political compromise for which all major parties made significant concessions. Successfully implementing the compromise will require recognition of these concessions, continuing public pressure in the U.S., Europe, and Japan, as well as strong political and financial support for UNEP. The battle for approval is far from won. The efforts of this Committee will be crucial to sustaining the current compromise, protecting the environment, and reducing the risk of ozone depletion. Although the Reagan Administration has taken a strong leadership role in the ozone negotiations, the Administration's efforts to reduce UNEP's budget inadvertently cripple those very efforts. If it is the will of the Congress to protect the ozone layer through an international agreement, it must pressure the Administration to support the strong position articulated by EPA Administrator Lee Thomas and increase the level of U.S. financial support for UNEP to its previous level of $10 million per year.

Encouraging the Use of Safe CFCs and Substitute Products

The production and use of CFCs has grown rapidly since their introduction in the 1930s. This increase has occurred because these chemicals have a variety of useful properties (e.g., they are non-toxic, non-flammable, and non-reactive). They perform many economically important functions in a wide variety of applications. Principle current uses include refrigeration, foam blowing, and solvent applications. Unfortunately, many of the capabilities which made these chemicals attractive initially are the same properties which contribute to their dangerous impacts on the environment.

Luckily, through the efforts of this Committee among others, the public is becoming aware of the risks of atmospheric modification due to human activities. At the same time, a new generation of products is emerging which may be able to substantially reduce the dangerous environmental consequences of continued reliance on the traditional CFCs. The two types of new products which show special promise are: (1) alternative CFC formulations which are less dangerous in the atmosphere either because they don't contain chlorine or do contain hydrogen atoms and (2) non-CFC products which can perform the same functions as ozone-depleting CFCs.

Dupont, Pennwalt, Halocarbon Corporation and others have recently indicated that they can now or will soon be able to produce safer alternative CFC formulations in commercial quantities. Matching the best of these new products with each of the myriad of present CFC applications will take time as well as careful study. Naturally, as with all new chemicals, extensive toxicity testing will be required. But WRI, for one, remains confident that with appropriate regulatory signals and market incentives, American ingenuity and technical skill can quickly bring these products successfully to market. We have been completely persuaded by Dupont that under these conditions, the new safer CFCs can be produced in commercial quantities in less than five years. Dupont has no special monopoly on engineering talent or ingenuity. If the management of other companies made similar commitments, they too could help rebuild American competitiveness and lead the way toward the next generation of safer CFCs.

One member of the "safe CFC" family, CFC 22, is already in widespread commercial use. Several other safe CFC compounds are waiting in the wings. The most promising among these compounds is CFC 134a, a potential direct substitute for CFC 12 in refrigerant applications. Patents for production of this chemical are held by Dupont, ICI of Great Britain, an Daikin, a Japanese company. Recent announcements indicate that CFC 134a is for the first time available in the U.S. market in quantities of thousands of pounds, the approximate amounts needed for toxicity testing. If these tests are successful, this chemical could be available for general commercial use in five years or less. Other promising candidates for safe CFCs include CFC 142b and CFC 152a, both potentially important as alternative refrigerants and blowing agents. Because all four of these alternate CFCs contain hydrogen atoms, they will have short lifetimes in the atmosphere and substantially lower ozone-depleting potential than the CFC 11 and CFC 12 which they will replace. Table 1, taken from the WRI report The Sky's Is the Limit, summarizes the status of the alternative CFC formulations.

Solvent applications of CFC 113 will be among the most difficult to replace. Some other types of bulk degreasing agents are now becoming available for metal cleaning applications which represent approximately 30 percent of total solvent applications of CFC 113.

CFC 113 applications in the electronics industry will be more difficult to replace. Recent progress by Digital Equipment Corporation and IBM provides the most promising results in this area. The use of aqueous cleaning solutions, combined where possible with ultrasonic rinsing in de-ionized water is attractive for many applications except those involving the smallest and most delicate devices. Application of these techniques combined with solvent recovery systems using carbon absorbtion filters could reduce annual solvent requirements for CFC 113 in electronics applications by up to 50 percent. Development of these technologies and their marketing to Japan could significantly reduce Japanese resistance to an effective protocol for the ozone convention.

The key objective of the policy process is to stimulate rapid development and deployment of these safe, alternative compounds. WRI supports a strong international protocol insuring 50 percent or greater reductions from 1986 levels not only because such reductions directly reduce the risk of ozone depletion but also because they will stimulate the introduction of the new and safer compounds.

These new compounds remain significantly more expensive to produce than CFCs 11, 12, and 113 because until recently they have only been produced in small laboratory quantities. To accelerate the introduction of these compounds and to internalize the environmental costs of the traditional, more dangerous CFCs, WRI recommends that the U.S. impose a user fee of $5 per pound on CFCs 11, 12, and 113. This fee would apply to bulk chemicals and to products including or made with CFCs. It should apply equally to domestic and imported production. Table 2, taken from the WRI publication The Sky Is the Limit, summarizes our estimates of the effect of a $5 per pound fee in reducing the demand for CFCs 11 and 12 in the U.S.

Trade Issues and CFC Regulations

CFCs are used in a wide variety of products and services: as a refrigerant; a blowing agent for rigid insulating materials and soft foams; and as a solvent with important applications in the electronics industry. (See Table 1.) In some cases, such as refrigeration and insulating materials, CFCs are tightly sealed within the product, while in other cases, such as soft foams and electronic components, CFCs are used in making the product and may not be detectable thereafter. The cost of the CFCs used in making products almost always represents a very small fraction of total product costs. However, the product may be designed around the performance characteristics of the CFCs, so that substantial equipment changes might be needed to use substitutes. CFCs therefore have an indirect economic value that greatly exceeds their direct cost to industry and consumers.

The economic importance of CFCs has naturally led to concerns about the potential trade implications of international and domestic regulations on CFCs. U.S. industrial users of CFCs worry that they may be at a competitive disadvantage if their competitors are able to continue using less expensive CFCs while the U.S. requires more expensive substitutes. They further argue that U.S. regulation that goes beyond international agreement may have little environmental benefit if it does not induce comparable action by others, as the U.S. is responsible for less than half of global emissions.

For several reasons, we believe these concerns are exaggerated. A strong international agreement is the clearly preferred outcome. The optional solution would involve an international protocol with free trade among the signatory parties and major restrictions on trade with non-signatories. In such an arrangement, the administrative burdens of enforcement would be minimal. High barriers to market penetration by non-parties would provide a strong incentive to sign and adhere to the protocol. One mechanism by which such a system could work involves a "commodities market" in CFCs. This market would cover all bulk chemical production of CFCs, supporting contractual exchanges between producers and users in the states signatory to the protocol. Such a market could be quite similar in concept and operation to other commodities markets now operating in future contracts for various commodities such as hog bellies and orange juice. By moving all bulk CFC production through such an international commodities market, signatory parties will reduce the risk of cheating on the protocol while incurring very low enforcement costs.

The U.S. market for many CFC products, such as computers and automobile air conditioners, represents a large share of the world market. Other countries must produce to our specifications or risk losing this market. Even unilateral regulations on these products are therefore likely to have a powerful effect on the world market.

The U.S. experience with regulating aerosol uses of CFCs has demonstrated that unilateral action can be effective where substitutes are available. The U.S. banned aerosol uses of CFCs in 1978, but the Common Market countries and many others continue to permit their use. While the U.S. does import substantial quantities of cosmetics, we have been unable to identify any indication of problems enforcing the U.S. ban on imports of aerosols using CFC propellants.

Enforcing regulations to limit use of imports of products made with or containing CFCs may be more difficult. Some products made with or containing CFCs are readily identifiable. The type of refrigerant used, for example, is readily determined. Less obviously, soft foams with a certain density can only currently be made using CFC as a blowing agent; foams of this density can be easily detected. Products like semiconductor chips that are made with CFCs, but do not contain CFCs after manufacture, will be more difficult to regulate.

Some types of regulations are also more easily implemented and enforced than others. A tax system could be uniformly applied to products presumed to be made with CFCs, subject to proof otherwise by the importer. Product bans would be the most directly enforceable. Regulation based on the compliance of other countries with emission limits is most difficult because it presumes both honest reporting and tracking of point of production.

In general, the administrative problems involved are comparable to, or less difficult than those raised by other domestic regulatory programs. For example, meat imports require annual inspection of over a thousand plants around the world. Millions of food imports from over 100 countries must be tested for pesticide residuals and other adulteration. Animal and plant trade requires detailed knowledge of endangered species in need of permits for importation. None of these systems is perfect, but they are all considered generally adequate to maintain the integrity of the domestic regulatory system.

The larger question, and more difficult to evaluate, is whether unilateral action can be effective without unduly penalizing U.S. firms. In the short-run, costs will be higher. However, as substitutes are proven and their costs reduced, it will become increasingly easy to demand their use by all countries wishing to operate in the U.S. market. Those firms that establish substitutes will thereby obtain a significant competitive advantage, just as U.S. manufacturers of catalytic converters now have a potential market edge in Europe. Indeed, European chemical companies have alleged that the U.S. is supporting a phase out precisely because it has a position of world leadership in producing safe CFCs.

In the absence of an effective commodities market it may be difficult to administer an international control protocol. If an adequate enforceable international agreement cannot be reached, we believe unilateral domestic regulations can be designed and enforced that do not impose severe economic costs on American industry. Properly structured U.S. regulations may even provide the U.S. with a significant long-run competitive advantage. Because American companies are capable of producing safe CFCs, they could lead the world to the next generation of chemicals. However, if we fail to develop these innovative technologies, we will no doubt soon be importing the safe substitutes from other countries.

Historically, U.S. leadership on environmental issues has been important to the evolution of international action. Our pressure no doubt had much to do with Japan's acceptance of the International Whaling Commission quota's, and their concern about the prospect of similar action in the ozone context is no secret. In contrast, it is difficult to cite an instance where our inaction motivated greater effort by other countries.

Conclusions and Implications for Policy

Regardless of the precise causes of the Antarctic Ozone Hole, enough is now known about ozone depletion worldwide to demand immediate action to regulate, reduce, and eventually eliminate the chemicals most threatening to the ozone layer. The U.S. and certain other industrialized countries currently consume close to five times the global per capita average of these chemicals. The industrial world has not only the responsibility to protect the Earth's ozone layer from manmade chemicals but also the capability to do it without significant economic and social disruption. Analyses conducted at WRI have demonstrated that achieving an immediate 30% reduction in the use of the most dangerous CFCs is easy and cheap. Reaching reductions of 50 percent below 1986 levels is technically feasible and requires clever engineering but requires no major new discoveries.

Emissions of the most harmful CFCs can be cut at least 50% below 1986 levels within five years by actions that will perpetuate both a healthy global economy and a healthy ozone layer. If U.S. industry accepts the challenge of developing alternative, safe CFCs, their efforts can buttress the national drive toward innovation and increased competitiveness. If the U.S. government fails to provide the right incentives and industry chooses to ignore this challenge to the global environment, it will be a sign of our unwillingness to confront the challenge of safe and sustainable development.

Table 1. Potential Short-Term Reductions in Emissions of Major CFCs for Less than $5 per Pound

Application	Est. 1985 Global Use (in thousands mt)	Methods for Reducing Emissions
Aerosols	93.7 (CFC-11) 115.6 (CFC-12)	replacement by hydrocarbons & non-aerosols CUT: 90%
Rigid foams	115.8 (CFC-11) 42.8 (CFC-12)	Substitute blowing agents; recycling CUT: 50%
Other foams	57 (CFC-11)	Substitute blowing agents; recycling CUT: 50%
Refrigeration & Air Cond.	9.9 (CFC-11) 24.9 (CFC-12)	Substitute refrig; recovery at disposal CUT: 25%
Mobile Air Cond.	73.4 (CFC-12)	reduced venting; recycling; tighter seals; CFC-22 test gases CUT: 25%
Solvents	163.2 (CFC-113)	Recover and recycling; substitute solvents CUT: 80%
Miscellaneous, Unallocated	23.6 (CFC-11) 108.3 (CFC-12)	CUT: 25%*
Communist countries	41.5 (CFC-11) 78.7 (CFC-12)	CUT: 33%*

*: Based on conservative assumption regarding actual mix of uses.

Source: Authors' estimates based on sources cited in text.

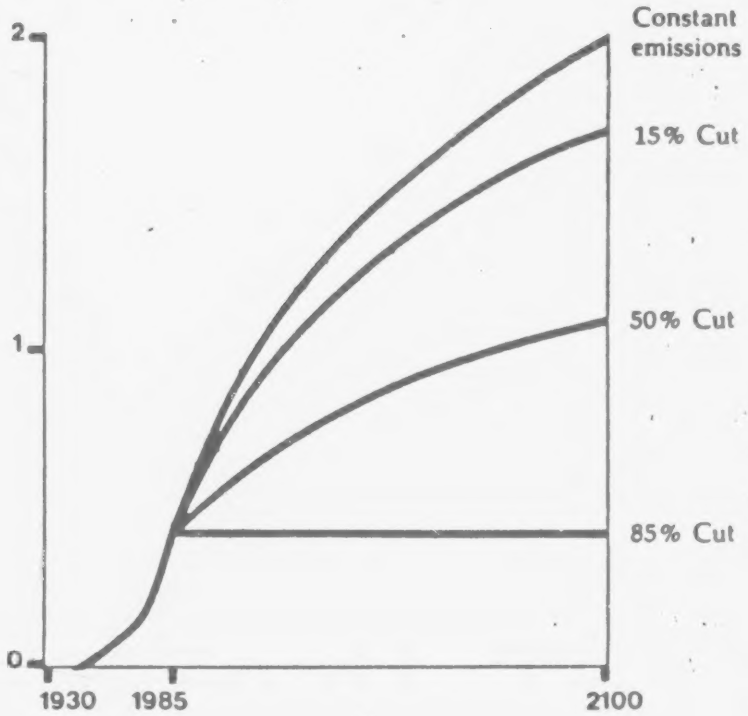
Table 2. Status of Alternative Fluorocarbons

Fluorocarbon No. & Formula	Potential Application	Manufacturing Process	Flammable	Toxicity
11 CCl_3F	Blowing Agent, Refrigerant	Yes	No	Low
12 CCl_2F_2	Refrigerant, Blowing Agent, Food Freezant, Sterilant	Yes	No	Low
113 CCl_2FCClF_2	Solvent, Refrigerant	Yes	No	Low
114 $CClF2CClF_2$	Blowing Agent, Refrigerant	Yes	No	Low
132b $CH_2C1CClF_2$	Replacement for CFC-113; too strong a solvent; Dropped	No	No	Very Incomplete
134a CH_2FCF_3 (a)	Replacement for CFC-12; Refrigerant, Others?	No	No	Incomplete Testing
141b CH_3CCl_2F	Replacement for CFC-11; Blowing Agent	Yes Developmental	Yes	Incomplete Testing
142b CH_3CClF_2	Blowing Agent, Refrigerant	Yes Limited	Yes	Low
143a CH_3CF_3 (a)	Refrigerant	Not Commercial	Yes	Incomplete Testing
152a CH_3CHF_2 (a)	Propellant; Refrigerant	Yes Limited	Yes	Low

(a) Contains no Chlorine

Source: DuPont, 1986, based on information available in February 1986.

Figure 1 CFC-12: Atmospheric Concentrations from Different Emission Trajectories (ppbv)



Atmospheric concentrations of CFC-12 will continue to rise unless emissions are cut. Holding emissions constant at today's level or even 15% or 50% lower would still allow atmospheric concentrations to grow. Only a cut of 85% or more could stabilize atmospheric concentrations.

Source: J.Hoffman, "The Importance of Knowing Sooner," in J.Titus, ed., *Effects of Changes in Stratospheric Ozone and Global Change* (Washington: EPA, 1986)

STRATOSPHERIC OZONE DEPLETION AND CHLOROFLUOROCARBONS

THURSDAY, MAY 14, 1987

U.S. SENATE, COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS, SUBCOMMITTEES ON ENVIRONMENTAL POLLUTION AND HAZARDOUS WASTES AND TOXIC SUBSTANCES,
Washington, DC.

The subcommittees met, pursuant to notice, at 10:10 a.m., in room SD-406, Dirksen Senate Office Building, Hon. Max Baucus (chairman of the Subcommittee on Hazardous Wastes and Toxic Substances) presiding.

Present: Senators Baucus, Reid, Chafee, Stafford, Symms and Durenberger.

OPENING STATEMENT OF HON. MAX BAUCUS, U.S. SENATOR FROM THE STATE OF MONTANA

Senator BAUCUS. The subcommittee will please come to order.

Ladies and gentlemen, welcome to the last in a series of joint hearings of the hazardous Waste and Toxic Substances and the Environmental Protection Subcommittees on the problem of stratospheric ozone depletion.

Over the past two days we have heard testimony that is both disturbing and comforting. Disturbing because our planet is courting global environmental catastrophe; but comforting in the knowledge that many fine men and women are studying the problem of ozone depletion in great detail. Their work has yielded much information and promise.

When we heard from industry yesterday, every company felt the potential threat was great enough to warrant action. To be fair, industry is supporting international action, not domestic action.

No one disagrees that worldwide action is needed to deal with the problem of ozone depletion. The question before us is: what action will we take, and will it be enough?

When the international negotiations on the ozone problem began in Geneva, the United States showed strong leadership. We took an effective position, calling for a freeze and a 95 percent reduction in emissions of all fully halogenated alkones—CFCs. Senator Chafee and I also have sponsored legislation calling for such strong and effective measures to protect the ozone layer.

Our distinguished chief of the Environmental Protection Agency, Lee Thomas, who is here today, attended the first negotiation session. Through his fine efforts the Europeans were convinced of the seriousness of this issue.

The U.S. continued to push for a total ozone protection strategy late last winter in Vienna. And because of our strong leadership, worldwide consensus for the U.S. position began to develop.

Then, something disruted the progressive atmosphere of the talks. Like the ozone layer, the U.S. position began to dissipate, poisoned not by "CFCs", but by "OMBs". Secret instructions from OMB had over-ridden a clear U.S. policy objective.

Stating that since it was responsible for leasing fossil fuels, and pointing to the connection between CFCs and gases associated with the "Greenhouse effect", the Department of Interior joined the fray.

Other Gremlins emerged to thwart the progress that had been made on the ozone issue. NOAA, the agency responsible for scientific support, apparently had staff at the negotiations working against what their own science supported.

What this all boils down to is that there are individuals in this Administration who apparently oppose protecting the ozone layer from further destruction; there are individuals in this Administration that don't care about the global threat we face.

I am pleased that Lee Thomas is here this morning. His agency, contrary to others, has demonstrated leadership, professionalism, and scholarship on the ozone issue. Many of the fine scientists who testified at these hearing have paid high tribute to the studies EPA has prepared.

This committee is concerned about protecting our environment, and the proper steps to achieve that goal. On the ozone issue, our charge is clear. The United States' position must be clear. It must be put back on track toward achieving significant reductions in emissions of CFCs into the atmosphere.

Reaffirming the U.S. commitment to tough, decisive action to protect the ozone layer is critical if we are to regain momentum in the world community necessary to achieve results. The U.S. must push for a freeze on emissions of CFCs at 1986 levels—an immediate freeze. And we must move as quickly as possible to cut emissions by at least 95 percent.

Today we will hopefully clear the air on the U.S. position on the ozone problem. That accomplished, we can begin moving forward again to clear the ozone.

Our witnesses this morning are Lee Thomas, Richard Benedick, and Anthony Calio.

Before you begin Lee, let's see if there are any opening statements from members who have arrived.

Senator Chafee?

OPENING STATEMENT OF HON. JOHN H. CHAFEE, U.S. SENATOR FROM THE STATE OF RHODE ISLAND

Senator **Chafee**. Thank you, Mr. Chairman.

At the opening of these hearings on Tuesday, I expressed my view that, despite the newspaper headlines, there was no agreement in Geneva on how to protect the ozone layer.

After running through some of the problems still facing our negotiators, I stated that "even minimally adequate, every remaining issue would have to be resolved in a manner that tracks the United

States' original negotiating position." And, those points were, "broad coverage of chemicals, tough trade sanctions, limited special treatment for developing nations, and reductions of no less than 50 percent in the rest of the world."

Then, we had the scientists come before us, and they told us in remarkably clear terms that, first, the global freeze on production of CFCs that is being urged by industry would result in depletion of the ozone layer. That is the first thing.

Second, even the most stringent option being considered at the international talks—the most stringent is a semi-automatic, that is, if it is going to be renewed and renewed by a certain vote, or not renewed by a certain vote—a semi-automatic 50 percent reduction, will result in significant depletion of the ozone layer; and

Third, what they said on the basis of health and environmental effects, there is no safe or acceptable level of ozone depletion.

Those are pretty straightforward, strong statements that they made.

That same evening, I saw an editorial from the Atlanta Constitution entitled "Regrettable Retreat On Ozone Front." I would ask that a copy be included in our record, and I would like to read some of it because it explains why our first panel of witnesses is here today.

This is what the Atlanta Constitution said,

> Just this once, the Reagan Administration was proudly out in front on an environmental issue, one of potentially cataclysmic dimensions, the thinning of the Earth's protective ozone layer.
>
> Suddenly, the stout U.S. stand in U.N. sponsored bargaining lost all its starch. The U.S. position, alas, was undermined by pressure from a CFCs industry group and from second-level Reagan appointees who adhere to ideas on safeguarding the planet's ecology that would have received a hospitable hearing from Attila the Hun.

Is that your hometown newspaper, Mr. Thomas?

Mr. THOMAS. No, sir. I only pass through Georgia, I never lived there.

Senator CHAFEE. After these hearings, the editorial concludes by saying—they mention the hearings we are having here,

> It won't be enough for the Senators to reveal how anti-environmentalist zealots and special industrial pleaders managed to derail an admirable Reagan Administration initiative. They ought to determine whether, if at all possible, the agreement offers any openings to get the effort back on track.

I am concerned about what was happening in our government during March and April, leading up to the Geneva meeting, but I am even more concerned about what may be happening now, before we go back to the negotiating table.

Who is deciding the environmental policies of our country?

Why are 18 agencies of the Federal Government meddling with EPA decisions on stringency and timing of controls?

Why aren't those agencies limiting their advice to issues that are within their area of expertise, such as trade or science?

Our job today is to figure out what position the U.S. has been advocating in the international talks and where we are going from here. I would have thought that the next step was an easy one.

The most stringent option that remains on the table in Geneva is a semi-automatic 50 percent reduction in CFCs. Remember, the U.S. began by advocating an automatic 95 percent phase-out.

How on Earth can the U.S. justify any position other than the one that advocates the most stringent option available, particularly since an international panel of scientists has shown that even the 50 percent reduction will produce a 5 to 10 percent loss of the ozone layer between the years 2050 and 2060?

How these issues are resolved will obviously affect the health and well-being of our planet. Not so obvious is the effect it will have on the leadership role of the U.S. in the world today, and on our ability to negotiate in the future.

With that, Mr. Chairman, I look forward to hearing from our witnesses, and certainly welcome them.

Senator BAUCUS. Thank you, Senator Chafee.

[The editorial referred to by Senator Chafee follows:]

[From the Atlanta Constitution May 12, 1987]

REGRETTABLE RETREAT ON OZONE FRONT

Just this once, the Reagan administration was proudly out in front of an environmental issue, one of potentially cataclysmic dimensions considering the dire and not easily dismissed predictions of pandemic skin cancer and genetic damage caused by the thinning of Earth's protective ozone layer.

You might even say President Reagan's men had picked up the torch from the Carter team, which in 1978 banned the use of chlorofluorocarbons (CFCs) in aerosol propellants, and were themselves on the verge of leading recalcitrant Europeans toward wider, more meaningful prohibitions that would have drastically and speedily reduced the production of CFCs worldwide.

Suddenly, the stout U.S. stand in United Nations-sponsored bargaining conducted in Vienna and Geneva over the last few months lost all its starch. The U.S. delegation wound up acquiescing in an agreement that would freeze CFCs production at 1986 levels, then slowly reduce it during the 1990s on a timetable that falls woefully short of the original U.S. targets.

The U.S. position, alas, was undermined by pressure from a CFCs industry group and from second-level Reagan appointees who adhere to ideas on safeguarding the planet's ecology that would have received a hospitable hearing from Attila the Hun.

Their position, charitably stated, is: Why hassle industrial concerns that produce vital chemicals for refrigeration, packaging, insulation and cleaning when the evidence of the environmental damage they might do isn't absolutely airtight and when chemical substitutes would cost substantially more?

Answers to these questions must be framed in terms of acceptable risks. Research in the Antarctic and elsewhere, while not conclusive, strongly points to CFCs as the culprits in the breakdown of the barrier that guards Earth from the sun's excessive ultraviolet rays. Reputable physicists also suggest that if we wait until CFCs could be found guilty beyond any doubt, irreparable damage might be done to the protective ozone layer. And, finally, it must be acknowledged that the economic impact of a CFCs phase-out pales against the possibility that inaction on our part might drive generations after us out of the sunlight and also might drastically disrupt their food chain.

Today a Senate environmental subcommittee chaired by Max Baucus (D-Mont.) begins a week of deliberations on the diluted accord brought back from Europe.

It won't be enough for the senators to reveal how anti-environmentalist zealots and special industrial pleaders managed to derail an admirable Reagan administration initiative; they ought to determine whether, if at all possible, the agreement offers any openings to get the effort back on track.

Senator BAUCUS. Senator Stafford.

OPENING STATEMENT OF HON. ROBERT T. STAFFORD, U.S. SENATOR FROM THE STATE OF VERMONT

Senator STAFFORD. Thank you, Mr. Chairman.

I will try to make my statement brief since Senator Chafee has covered the waterfront here.

Let me express my appreciation to the Administrator of EPA, Lee Thomas, and to Ambassador Benedick, for unrelenting support thus far of what is clearly the most prudent policy, despite what we have heard is tremendous pressure from OMB, the CFC industry, and other executive branch agencies.

Secondly, I must express my disappointment at the treatment so far by the producers and users of chemicals that attack the ozone layer for a business as usual attitude toward one of the most serious threats facing the planet.

If the scientists are correct, and virtually all of the evidence has come in on their side, not on the side of industry, the threat posed by these chemicals is of biblical proportions. At this time, there is no Noah's Ark.

Finally, allow me to express my hope that the Congress and the American public will be allowed to share in the deliberations as to what should or should not be done about CFCs and other chemicals destroying the ozone shield.

There is a disturbing trend, it appears, towards discussions behind closed doors, which we believe is an ill-advised policy.

Thank you, Mr. Chairman.

Senator BAUCUS. Thank you, Senator Stafford.

Senator Symms.

OPENING STATEMENT OF HON. STEVE SYMMS, U.S. SENATOR FROM THE STATE OF IDAHO

Senator SYMMS. Thank you, Mr. Chairman.

Gentlemen, I welcome you to the committee this morning.

Mr. Chairman, once again I commend you for this series of hearings on the issue of ozone depletion. In this the third and final day of the series, the subcommittees are going to hear from the Administration and the representatives that are currently working on the international accord on this topic.

I would like to be one that would give my congratulations to the U.S. delegation to those talks, and welcome the progress they have made in Geneva toward developing a protocol for the protection of the ozone layer.

In light of this progress, I am strongly concerned about the adverse impacts that would occur if this forum is used to publicly debate the U.S. position in these talks, especially as there are representatives of the other countries in the audience, who may be here, who we may have to negotiate with.

These representatives will undoubtedly report to their capital and perhaps reevaluate their positions based on the information from this hearing today.

I see a parallel to this with what is happening on the Senate Floor with respect to the Armed Services Committee bill. It appears to me that President Reagan should call his negotiating team back from Geneva on the arms control with the Soviets and have them first negotiate with the U.S. Senate before they go over, so we can have a common front.

I will just say to those of you who are negotiators that you know that you don't want to let the other side know in advance what your bottom line position is for negotiations. Providing that kind of information will weaken our national position and, in my view, could severely undermine the achievement of these goals.

Foreign countries, who assume that the U.S. will bear the lion's share of global CFC reduction, will lack the incentive to accept a significant CFC reduction of their own.

I think this is a problem, so consequently, as one member of the committee, I would like to caution the witnesses to refrain from any answers that weaken your position, and weaken the position of the United States for the long-term on this question in the negotiations.

Secretary Hodel, unfortunately, is out of the city and not able to testify, and an acceptable substitute witness was not found. I would request of the Chairman that the record remain open for about a week to ensure that Secretary Hodel's testimony can be submitted to be included in the record.

I hope we can do that Mr. Chairman?

Today, the subcommittee will also be hearing from those who will most be effected by a regulatory limitation on CFCs, those whose livelihoods depend on CFC products. I would urge my colleagues on this subcommittee to pay close attention to their concerns.

As we heard yesterday, alternatives to the most widely used CFCs are not readily available, and they potentially carry toxic and occupational hazards of their own, and at the very least are many times more expensive.

It has always been my position that the Federal government has no right to intervene and burden a man's livelihood unless there is some definite and overriding threat to the general populace that can be averted by doing so.

Since our knowledge and understanding of the precise threat of CFCs is far from definite, we should proceed in this area with great caution. After all we have no guarantee that burdens from regulations will provide overriding benefits. In such a case the Congress is, in essence, gambling, with the economy of the Nation and the livelihoods of thousands of individuals.

Mr. Chairman, I once again thank you for holding these hearings and allowing me to have this moment to state my views.

Thank you.

Senator BAUCUS. Thank you, Senator.

Mr. Thomas, why don't you begin.

STATEMENT OF HON. LEE M. THOMAS, ADMINISTRATOR, ENVIRONMENTAL PROTECTION AGENCY

Mr. THOMAS. Thank you, Senator.

I appreciate the opportunity to be back with the committee to speak about an issue that is extremely important, and to talk about the progress that I think has been made in dealing with this issue since the last time we discussed it.

As you know, or as I discussed at the last hearing, I have personally dealt with the issue of stratospheric ozone as Administrator of EPA over the last two and a half years. During most of that period of time, I have gone forward to implement a process, which I worked through and established, and did so in the context of a consent decree under a court order related to this particular issue that was both a risk assessment process and a risk management process.

I would like to briefly describe that. It is described in more detail in my written testimony, but I will highlight it here.

The risk assessment process that was recently was one that had extensive international and domestic participation by scientists from a number of agencies, NOAA, NASA, National Science Foundation, scientists outside of the Federal government, and the international community.

It was a risk assessment process that was clearly established both in the context of our authorities in the United States with the participation of the United Nations environment program, and other international bodies.

You heard much of the assessment from the scientists in the last couple of days that we heard in the context of that risk assessment. We not only assessed what we felt was the state of the science, but what the effects of depletion may be.

We completed that risk assessment and established a peer review process with scientists outside of the Federal government, scientists that are a part of our Science Advisory Board to review that risk assessment.

They basically concluded that it was a commendable task. It had covered the issues well, both on the assessment of the state of knowledge concerning depletion, as well as the state of knowledge concerning the effects of depletion, and issued an overall report to us concerning our risk assessment.

We had extensive input during that entire risk assessment process from not only international scientists, but scientists representing industry and the environmental community, particularly in the United States. Based on that risk assessment process, we proceeded with a risk management approach.

I, for one, concluded that management of the potentially depleting chemicals was appropriate. I concluded that we needed to manage those chemicals, particularly in the international context in which they were produced and used, and that we would not necessarily take unilateral action in the United States, but not preclude that action either.

In the context of the agreement, I made under the consent decree, I, in fact, must make that decision, and recently have moved to get an extension on that decision, from this past May 1st to this upcoming December 1st, to determine whether unilateral action would be required in the United States or, in fact, whether we are able to go forward and, hopefully, implement an agreed upon international protocol.

The risk management process began, and it has been, as you know, an active one over the last several months. Let me speak specifically to the international process from our point of view.

The United States' position was one that was developed based on our assessment of risk, based on how we felt the issue should be dealt with, in full coordination with the State Department and other agencies in the executive branch.

It is a position that I have discussed before several committees and subcommittees of the Congress, and certainly a position that I have discussed with counterparts in countries around the world.

We suggested, and incorporated in that position, that all fully halogenated depleting chemicals, particularly chlorofluorocarbons, but also Halons, should be incorporated in a control agreement.

Particularly as we look at growth in some of the new chlorofluorocarbons and Halons, we were concerned about not incorporating those. We felt that we should have the broadest coverage possible in our agreement. We felt that a freeze was appropriate on production of those chemicals, and we felt that we should move towards a phase-out of those offending chemicals.

How far and how fast we needed to go should be determined by a full scientific, technical, and economic review process, which should be established and should be ongoing. So the 95 percent was an up to 95 percent. The time frame was a 10 to 15 year time frame. The how much and how fast was to be determined by the scientific process.

We have gone through three tough negotiating sessions internationally and, in my opinion, we have made good progress. But, as Senator Chafee stated, there is much more progress to be made if, in fact, we are going to have a strong international agreement.

I believe that in nearly every element of the negotiating process, there will need to be further progress in definition, if we are to get that agreement and get it in the time frame that we are working towards, which is, hopefully, in September in Montreal.

As Senator Symms noted, it is not a time where we air all of the components of that agreement and the debate that is going on about elements of that agreement in and out of government. We have a strong position, the United States' negotiating team.

It is the same strong position we have had in the past. It is the same strong position we take into the negotiating session, let's incorporate all of the offending chemicals. Let's freeze those chemicals at 1986 levels. Let's work towards a phase-out of up to 95 percent.

Let's set a scientific, technical, economic assessment process that is ongoing to determine how fast and how much that phase-out needs to be done, and let's move forward with tough components in the other parts of the agreement relating to growth in developing countries, related to trade restrictions as far as those countries who do not participate.

I believe we can get a good, strong international agreement out of this process, and I believe it is essential, to deal with the problem of stratospheric ozone depletion, that we do get a good strong international agreement.

Notwithstanding that belief, I am prepared to make the decisions about whether domestic action is required. In fact, the analysis as to whether domestic action is required, with or without an international agreement, is ongoing, and I have committed to make a decision on that now in the December time frame.

So, I am very hopeful that the domestic decision will be one to implement a strong international agreement.

I appreciate the opportunity to be with the committee and respond to any questions the committee may have about where we are going and where we hope we will end up in dealing with, I believe, one of the most important environmental concerns of today.

Thank you.

Senator BAUCUS. Thank you very much, Mr. Thomas.

Now we will hear from the Honorable Richard Benedick, Deputy Assistant Secretary for Environment, Health, and Natural Resources for the Department of State.

Mr. Benedick.

STATEMENT OF HON. RICHARD BENEDICK, DEPUTY ASSISTANT SECRETARY FOR ENVIRONMENT, HEALTH, AND NATURAL RESOURCES, DEPARTMENT OF STATE

Ambassador BENEDICK. Thank you, Mr. Chairman.

I am also delighted to appear again before this distinguished body, and I would like to start by saying that I agree in full with what Lee Thomas has said about the need for an international protocol to protect the ozone layer, about the progress that has already been made in the international negotiations, about the difficulties that still lie ahead in these negotiations, and finally about the essential inadvisability of debating in great detail the interim positions, or the debate that may be taking place on particulars of this protocol within the United States Government.

Since we last convened to consider this subject in January of this year, there have been, as you know, two further rounds of formal negotiations, one in Vienna, in February, and the last one just two weeks ago in Geneva. But behind these events is the story of intense activities by the United States Government to advance our overriding objective, which is the achieving of an effective international protocol to prevent harm to the ozone layer.

We have undertaken extensive bilateral consultations with other governments. Science policy delegations have traveled abroad to hold discussions at ministerial and sub-cabinet level with the British, the Soviet, the French, the Belgian, and the Japanese Governments, and with the European Commission.

NASA's Senior Scientist, Robert Watson, and I have employed the United States Information Agency's Worldnet video conference technology to reach out to audiences in Japan, Canada and throughout Europe. I and others have held press conferences and radio interviews here and abroad. As has been pointed out, there has been a tremendous interagency effort within our own government here in Washington to further examine the many faceted aspects of an ozone protocol.

Mr. Chairman, the breadth and the intensity of the interagency deliberations far from being a sign of weakness or undercutting is a testimony to the importance of this issue, and also the seriousness with which the Administration takes it. Our interagency process has refined and strengthened the analytical and policy underpinning for the United States position.

I personally have appreciated the wise counsel and strong support which I received in Geneva last month from all members of the large and knowledgeable United States Delegation, which comprised representatives of the Environmental Protection Agency, the National Aeronautic and Space Administration, the National Oceanic and Atmospheric Administration, the United States Trade Representative, the Departments of Commerce, Energy, and the Interior, and the State Department's legal advisor.

This delegation was supported by an even larger number of agencies and individuals back home in Washington, one of whom told me that for them the most welcomed aspect of our week in Geneva was that no interagency meetings on ozone had to take place in Washington during that time.

Mr. Chairman, the United States position in these complex negotiations has benefited from the expertise of these agencies, and I am confident that their support will be equally significant in the difficult international negotiations that lie ahead.

I would also here like to acknowledge the importance and responsible advice that we have been receiving from a wide range of American industry representatives and U.S. environmental organizations, as well as from members and staff of the U.S. Congress.

I am pleased to report to you that in large part, due to this extraordinary combined U.S. effort, there has been substantial progress in the negotiations. At the last round in Geneva, April 27th through the 30th, under the vigorous and effective leadership of Dr. Mustafa Tolba, who is the Executive Director of the United Nations Environment Program, there occurred a significant narrowing of hither to widely divergent views among participating delegations on what an international protocol might look like. This convergence of views begins to resemble, both in structure and in quality, the illustrative protocol text which the United States Delegation offered last December as a basis for discussion and exploration.

However, I should emphasize to you that there are still important differences separating the United States' position from the European Community's, Japan's, and the Soviet Union's. It is clear that further negotiations will be difficult, but I would like to make very clear to you that the United States' position remains unchanged.

Our objectives remain now as when these negotiations began, based on the following three fundamental elements:

First, the near term freeze at 1986 levels of all fully Halogenerated, alacadence, including Halons, weighted collectively according to the ozone depleting capacity of each individual compound.

Second, longer term reduction of these chemicals, step by step, down to the point of eliminating emissions from all but limited uses for which no substitutes are commercially available, and this schedule being linked with regular reviews of the science, economics, and technology to enable the parties to rationally implement the reduction schedule.

These principles, Mr. Chairman, were the essence of the U.S. position that I presented to the international community on December 5th, and they continue to be our theme as we prepare to complete the negotiations and to sign an effective international protocol for protection of the stratospheric ozone layer.

Thank you, Mr. Chairman.

Senator Baucus. Thank you, Ambassador Benedick.

Next, the Honorable Anthony Calio, Under Secretary of Commerce for Oceans and Atmosphere.

Mr. Calio, why don't you proceed.

STATEMENT OF HON. ANTHONY CALIO, UNDER SECRETARY OF COMMERCE FOR OCEANS AND THE ATMOSPHERE, DEPARTMENT OF COMMERCE

Mr. CALIO. Thank you, Mr. Chairman.

I am delighted to have the opportunity to be here this morning as well, for the first time that I have been here.

What I want to state clearly is that as far as the agency I represent, we strongly support the objectives as stated by Mr. Thomas, and the objectives in trying to reach some agreement with respect to international protocols.

For purposes of today's discussion, my testimony will highlight the current understanding about the chemistry and dynamics, and the appropriate role that science plays in the formation of public policy.

I am providing a summary, which I would like to have included in the record, of NOAA's current and planned research efforts which, coupled with the testimony given by Dr. Susan Solomon and Adrian Tucker earlier this week, will give the subcommittee a good overview of NOAA's atmospheric science and research activities.

From a scientific perspective, any proposed regulatory policy should consider all of the fully halogenated chlorofluorocarbons and Halons as a group characterized by high ozone depleting potential and long lifetimes. Consideration also should be given to the atmospheric growth rates of other trace gases, such as carbon dioxide, methane, and nitrous oxide, which can influence the response of stratospheric ozone to CFC and Halon emissions.

The current understanding of stratospheric chemistry and dynamics predicts that the total column amount, as well as other redistributions of atmospheric ozone, respond to the total chlorine and bromine loadings of the stratosphere. Current model predictions for emission growth scenarios show global column ozone losses within the next 75 years that are larger than or equal to the observed natural, long-term variability, that is, around 2 to 3 percent.

Most atmospheric scientists believe that if the current growth of chlorine and bromine containing compounds continues unabated indefinitely then it is likely that these ozone depletions will occur. They also believe that even with a global freeze, 20 to 25 percent depletion of upper atmospheric ozone is likely to occur within the next 75 years, which could influence global climate change.

In terms of ozone trends observations, there is no compelling evidence in the existing ground-based and satellite data sets of a chlorine induced ozone depletion. Inconsistencies in the data sets and the possibility of instrumental artifacts have divided the atmospheric science community as to the reality of any human caused loss of global column ozone.

NOAA is participating in a reassessment of these data sets with plans to report the results in the fall. We are participating with the National Science Foundation and the National Aeronautics and Space Administration, as well as EPA.

Scientific discoveries continue to be made and concentrated efforts to improve the understanding of what has been discovered advance the state of knowledge on an almost daily basis. In order to have a sound policy, a constant reassessment of our knowledge is absolutely necessary. Policy cannot be divorced from science.

NOAA participates with many other agencies in the current international negotiations of a CFC/Halon protocol and will strive to provide the complete scientific advice needed to base these negotiations on a current understanding of atmospheric circulation and chemistry.

NOAA, based on the current understanding of science, supports two premises, and they were stated earlier:

A true global freeze, at current levels of production, on the sum of all fully halogenated CFCs and Halons. Such a freeze is predicted to limit the average column-ozone depletion to 1 to 2 percent, which is on the scale of natural variability.

Second, a reduction in global emissions, within the next ten years, based on our understanding of the science, sufficient to limit the predicted long-term loss, in the year 2050, of stratospheric ozone from vertical redistribution and column ozone at high altitudes.

NOAA will continue its vigorous scientific research in coordination with other agencies to address the processes that influence atmospheric ozone. The research and monitoring activities NOAA is undertaking are going forward with outstanding cooperation and collaboration with many other agencies, as you well know, and the scientists participating in these efforts are first rate, as you also know. Any public policy which evolves must be based on their work, and any international negotiating position must be predicated on the science.

Mr. Chairman, I would be pleased to answer any questions that you and members of the subcommittee may have.

Thank you.

Senator BAUCUS. Thank you very much, Mr. Secretary.

Mr. Thomas, what did the EPA risk assessment show the threat of CFC emissions to be on the stratospheric ozone depletion.

Mr. THOMAS. The basic effects that were outlined in the EPA risk assessment were the effects of an increase in the UVB radiation as far as the atmosphere is concerned, and the effects were those of increased skin cancers, the most dramatic as far as health is concerned, and the ones that probably had the most scientific basis for drawing direct conclusions, both nonmelanoma skin cancer and malignant melanoma cancer.

Beyond that, it also talked about effects on immune systems as far as health effects are concerned. It talked about effects on aquatic and other environmental elements. It talked about effects as far as overall welfare, particularly crops losses concerned with increases of atmospheric ozone.

It laid out a range of effects. It also laid out, I think, where there was scientific strength and scientific weakness as far as the assessment of those effects is concerned. I think regarding the skin cancer effects, there was probably stronger evidence there of the impact in the increase of UVB radiation than there was, for instance, on potential effects on the immune system.

Senator BAUCUS. Was that risk assessment the basis of the U.S. position in the international arena of a freeze at 1986 levels, and then working toward a phase out of up to 95 percent emissions?

Was the EPA risk assessment the basis for that position?

Mr. THOMAS. It was a major element in the decision, but I think that what is evident from our risk assessment, as well as the ongoing discussions of the science, as Mr. Calio pointed out, is there is considerable uncertainty on both sides of the risk assessment, both the assessment of what is happening and what may happen as far as stratospheric ozone is concerned, as well as debate on what the effects may be.

I think, as we have looked at that, and incorporated it in our risk assessment and as we participated in the international community, both the World Meteorological Organization, and the United Nations Environment Program assessments, we came to the conclusion that the evidence was such that action was required now.

Even though we couldn't draw conclusive evidence that we already had ozone depletion resulting, clearly our models indicated, and I think there was scientific consensus internationally, that there would be stratospheric ozone depletion in future years, particularly because of the buildup of these chemicals in the stratosphere, resulting from the long lifetimes of these chemical molecules which are anywhere from 50 to 125 years and the fact that we have substantial growth in those chemicals. All the models indicated that if we didn't begin action now, we would clearly begin to see repetition in future years.

This is an issue where, I think, the prudent course is a course that is a prevention course today. Corrective action will be virtually impossible in the future because of the dramatic costs that would be required if we began to see ozone depletion, which we may begin to see as a result of scientific information we are gathering, as Dr. Calio indicated, in a reassessment of ground-based data, as well as the Antarctic ozone hole data that is coming.

Senator BAUCUS. Is it the imminent threat of the buildup that led EPA to arrive at the up to 95 percent phase out; or what is it that led up to that conclusion of the up to 95 percent phase out?

Mr. THOMAS. It was the conclusion that when you look at the information that the scientists gave us that we may well need to phase out the majority, if not all, of the chemicals that have high depleting effects. We didn't know enough today, in our opinion, to say that has to be done.

We didn't know enough today to say that it had to be done in 5 years or 15 years, but we did know enough today to suggest that we needed to begin moving towards that goal, that we needed to have far better scientific and technical information on the effect of that, and we needed to set up a step down process to get to that goal based on improved scientific information.

Senator BAUCUS. Did the Wurtzburg Conference strengthen or weaken the U.S. position of the 1986 level freeze with a phase out of up to 95 percent?

Mr. THOMAS. I must say that I think all of the international conferences on this issue over the last two to three years that I have read reports of support the U.S. position of concern and increasing scientific information to support the direction that we have suggested for an international agreement.

Senator BAUCUS. Has there been any recent scientific evidence since the EPA risk assessment or since the determination of the

U.S. position, namely, the 1986 freeze with a phase out of up to 95 percent?

Has there been any recent scientific evidence that would detract from or contradict that position since that position was determined?

Mr. THOMAS. You have seen it in the hearings you have had, this on-going discussion and debate about these issues. It is a natural process, particularly on an issue as complex as this one, but I have not seen anything that has suggested to me, from the scientific community, that I should move away from the position that I have taken.

Senator BAUCUS. Obviously, there is conflicting evidence because there is no certainty in this area, and there never will be certainty, but on balance does the evidence tend to support or tend to detract from the position of the 1986 freeze, with a phase out of up to 95 percent of the present emissions?

Mr. THOMAS. I think, if you link the components of the U.S. position, and it is critical that they be linked, that is, fully halogenated CFCs and Halons, the up to 95 percent over a 10 to 15-year time frame, with a clear proviso of scientific, technical, and economic review to determine when and how fast, and whether we need to go that far. I don't see anything that has detracted from that. In fact, I think it has supported that position.

Senator BAUCUS. Thank you.

Senator Chafee.

Senator CHAFEE. Thank you, Mr. Chairman.

Mr. Thomas, in your statement, you say that the U.S. position is not based on the likelihood that the Antarctic hole is caused by CFCs, and that is on page 3 of your statement. You say,

> This year's scientific expedition should continue to expand our understanding of the Antarctic ozone hole. Because the implications are still not well understood, the U.S. negotiating position is not based on this phenomenon.

They are going down there on August 10 or August 20, whatever can be worked out. I wouldn't expect that they could have their information correlated and their conclusions reached until perhaps late October.

You, yourself, have known these scientists for many months, and some of them work for Mr. Calio. They expect that the smoking gun is going to be the chlorine and the CFCs. How is that going to affect our position in Montreal, because the timing there is scheduled for September, I believe that it is September 11th to the 14th. Yet, this rather vital information will be coming in right after that.

My question to you is: Has anybody given any thought to waiting for this very telling information?

Suppose we reach an agreement in September, and everybody says, now we have this locked in, and we are going to go to a 2-year, but then we find, when the information comes in in October, that the situation is far worse than anybody ever dreamed about. Where does that leave us? Where does that leave not only us, but the world?

Mr. THOMAS. Senator, this is the second expedition to the Antarctic. They went last summer, and there was some discussion as to whether we should wait for last summer's information to proceed with the U.S. position.

As you stated, our position was not based on that Antarctic information. We felt that it could accommodate what came out of any kind of Antarctic finding.

I am concerned about waiting to go forward with an international agreement. I am concerned about this over the horizon that is going to give us better information one way or the other. Based on the assessment of risk that was done by the scientists, as you know, and that I indicated—participated in—we participated in internationally, I thought there was evidence that we needed to move forward with the process now, which obviously is a time consuming process internationally, to reach agreement, a process that could be modified over time as we improved our scientific information, either to back away from some of my goals, because we find that they are not required, or to move up our time frame or strengthen our goals because we find that they are not strong enough.

If the Antarctic information comes in, and there is requirement from that information to move more vigorously with our agreement, I feel that the scientific process we are setting up, the review process that we are setting up in this international protocol, that we then can review and determine whether we should strengthen the goals in our overall agreement.

I don't think we ought to wait on an international agreement until that expedition, or another expedition, or somebody's analysis of data is completed because it will provide us some better information.

Senator CHAFEE. It certainly would be contrary to the position of this committee, or certainly the statements I have made here, to suggest waiting, because, as you know, this committee is constantly lecturing you and witnesses that scientific information is ever going to be perfect, we have got to move ahead with what we have. So I think that what you say makes a lot of sense.

Mr. Calio, you quote, I assume with approval, because you quote it, on page 2—

> Most atmospheric scientists believe that if the current growth rates of chlorine and bromine containing compounds continue unabated indefinitely, then it is likely that ozone depletions will occur. They also believe that even with a global freeze, a 20 to 25 percent depletion of upper stratospheric ozone is likely to occur within the next 75 years, which could influence global climate.

That is pretty frightening, and yet you seem to feel that a global freeze is fine. How do you justify that position?

Mr. CALIO. There are two components in that. I will start it, and I will ask for the assistance of a gentleman I have with me.

The two components in connection with the freeze, the notion there is that in freezing all of the fully halogenated CFCs and Halons as a group, and I commented about those which contribute to high ozone depleting potentials, if we freeze those now, what we would do, we would be able to hold the depletion of ozone to what is known about 1 to 2 percent in natural variability, that is, the ozone varies between 1 and 2 percent naturally.

We try to discern the difference between man-made production of activities and natural variability. Just stopping it there, we will be within the natural variability.

The next thing that happens, however, it has been predicted recently that there is a depletion at the higher altitudes and an expansion at the lower altitudes. That is the reason for the second statement that there is something taking place as far as redistribution is concerned in the atmosphere, both at high latitudes and altitudes, even if you hold the chlorine emissions to where they are now and the ozone variation to where it is now with the natural variability, and those are predictions that have been made over the last few years.

Senator CHAFEE. My time is up, but the scientists got into that business of relying on the total column, and we will get into that later.

Thank you.

Senator BAUCUS. Senator Reid has joined us. Senator, do you have an opening statement that you would like to make at this point?

Senator REID. I do not, Mr. Chairman.

Senator BAUCUS. Senator Stafford.

Senator STAFFORD. Thank you, Mr. Chairman.

Mr. Thomas, as you know, I have written to you and your counterparts in the Executive Branch seeking information on the role industry and industry spokesmen played in recent changes in United States policy in the international negotiations.

An official of the White House informed me yesterday afternoon that there were some difficulties in providing the requested information within the time specified.

Mr. Chairman, I would ask unanimous consent that a sample of the letters I referred to be made a part of the record at this point.

Senator BAUCUS. Without objection, so ordered.

[The letter referred to follows:]

QUENTIN N. BURDICK, NORTH DAKOTA, CHAIRMAN

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United States Senate

COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
WASHINGTON, DC 20510-6175

May 7, 1987

Honorable Donald P. Hodel
Secretary
Department of Interior
18th and C Street, N.W.
Washington, D.C. 20240

Dear Mr. Secretary:

This is to request a report of all communications to or from your staff within the last six months seeking to influence either the on-going rule-making at the Environmental Protection Agency or the conduct of the international negotiations with respect to the control of chlorofluorocarbons and other ozone-depleting substances.

On May 17, 1986, the Federal District Court for the District of Columbia ordered the Administrator of the Environmental Protection Agency to sign, not later than May 1, 1987 "a Federal Register notice proposing regulatory action on CFCs or presenting a basis for a proposed decision to take no action." It is my understanding that since that time, the staff of the Environmental Protection Agency has been preparing a regulatory proposal. Concurrently, and in collaboration with other agencies of the Executive Branch, EPA staff and the Administrator personally, developed the United States position for the Convention for the Protection of the Ozone Layer.

In the international negotiations, the United States enjoyed considerable success, reportedly to the surprise of the manufacturers and users of CFC's and other ozone-depleting substances. Recently, there have been numerous press reports that the industry, and others representing industry interests, were seeking to, according to one account, "pull the U.S. back." There have been rumors and reports of industry groups, Executive Branch agencies, and others seeking to influence either the negotiations or the regulations or both.

Although it is my understanding that such attempts are not, in and of themselves, a violation of the law, it is also my understanding that these communications must be made publicly known through docketing or otherwise. Quite aside from the requirements of the law, the Administrator of the Environmental Protection Agency has assured the Congress that such decisions would be made in a "fishbowl". OMB executives have committed to maintaining records of communications received as well as those transitted to other agencies with respect to influencing environmental regulatory decisions.

Therefore, I would appreciate a report of all communications, whether written or oral, and meetings which were related to either the development of Federal regulation of CFC's or the United States negotiating position prior to the April 27-30, 1987 session in Geneva, Switzerland. The report should encompass communications between your staff and representatives of the users of CFC's; producers of CFC's; and any other persons whose communications are considered to be ex parte communications when made in the context of rulemaking or other proceedings. Such individuals would include, but not be limited to, representatives of environmental organizations, non-profit groups, and other branches of government.

It is my understanding that the members of your staff most actively and directly involved in these matters are Rebecca Norton Dunlop and Martin Smith.

For each of these individuals, I would appreciate knowing the date on which meetings were held, the attendees, their affiliations, and the subject matter which was discussed. Comparable information should be provided with respect to telephone conversations and written materials. In all cases in which either the development of regulations or the United States negotiating position were discussed, please state what position was being advocated by each party and, in any cases in which written materials were circulated, provide copies. This request is not limited to those cases in which factual information was conveyed, but specifically includes those in which opinions or policies were urged. It also includes any documents or other materials which are effectively equivalent to policies, such as oral or written instructions to those responsible for developing, implementing, or negotiating policy.

I recognize that this is an unusual request. But it has been widely reported and rumored that the United States position on further regulation of CFC's has been the subject of extraordinary pressure from industry groups and their spokesmen. It has also been reported and rumored that in response to these pressures the United States position has changed, not as a result of negotiations with other nations, but because of these industry arguments. Whatever any individual's view on the need for the regulation of CFC's or other substances may be, the arguments should be made and the merits debated in public. That is especially true in circumstances such as this where the global environment is at risk.

Because hearings on this subject have been scheduled for May 12, 13, 14, I would appreciate receiving your reply by not later than close of business of May 12, 1987.

Sincerely,

Robert T. Stafford

Robert T. Stafford
Ranking Minority Member

RTS:cmp

Senator **Stafford**. Mr. Thomas, if it is possible for you to do so, I would like to know by what date the committee could receive the documents and other information which I requested in the letter to you and to the other various secretaries of the cabinet?

Mr. **Thomas**. Senator Stafford, as you indicated, the process of trying to look at the information you requested and to determine how it could be pulled together is one that a number of agencies are working on, including coordination by OMB, which works on, as you know, coordination of provision of information to the Congress.

The process within our agency of actually beginning to pull together that information is underway. I must tell you, you have requested extensive information, which would require a great deal of fresh data gathering to go back and try to establish communications of all kinds.

We have had an extensive input process, whether it is industry, environmental organizations, other governments, other agencies, and it is one that would require an extensive amount of time and effort. I can't give you a firm date today.

Senator **Stafford**. All right. I realize that we have asked for extensive information, but it is important to us that we see it as soon as possible.

Do you still believe personally that the most prudent and best policy is a freeze on CFCs, and other ozone depleting chemicals followed by a 95 percent phase out?

Mr. **Thomas**. Senator, as I have indicated, the position that the United States Government has taken, the position that I have supported from the beginning is one that links the three elements of which chemicals are incorporated, moving from a freeze to up to 95 percent reduction, depending upon the scientific review process.

We are in the midst now of negotiating internationally an agreement that is trying to work on defining those steps in-between the 95 percent or a virtual phase out and the freeze, both in terms of timing, in terms of how those actions will be taken, in terms of how we will use the scientific data that I think is being collected and, as has been stated, is improving dramatically with the kind of attention that this issue is being given.

I agree with the original U.S. position, and it is still the U.S. position. It is still the position from which we are negotiating. I think that as a result of it, we have made progress internationally.

Senator **Stafford**. Ambassador Benedick, the United States negotiating position at the December, 1985, meeting in Geneva was a freeze followed by a phase out. The U.S. position was the same at the second meeting in Vienna. The third meeting was held in Geneva three weeks ago, and at that meeting, you were our chief negotiator.

Did your instructions allow you to accept, should the other nations have agreed, a freeze followed by a phase out, which was the U.S. position at the first and second sessions?

In other words, were you free to accept a yes for an answer from the other nations present?

Ambassador **Benedick**. Yes, Senator. The U.S. position, as I indicated in my statement, did not change from December, 1986, up until the present date. We were, have been, and are continuing to pursue that 95 percent figure as an ultimate objective.

However, I should point out that it is not a magic number. As Lee Thomas has said, it is a direction. It is something to give a focus to the negotiations. We had no change in that in Geneva.

Senator STAFFORD. So that if the other nations had agreed to that position, you were in a position to say, okay, we have an agreement. Is that correct?

Ambassador BENEDICK. That is correct. There were no other countries, I might say, at Geneva who picked up that 95 percent figure, or at Vienna two months earlier.

Senator STAFFORD. Mr. Thomas, what is the status of toxicity testing on CFC 134A, and could you tell us how long it might be before it would be completed, if it is in progress, and could you tell us now, or in writing, if necessary, what tests are being conducted or planned, and also what is the current production capacity of CFC 22, and how rapidly could it expand. If you would prefer to answer those in writing, that is agreeable.

Mr. THOMAS. Senator, if I could give you a written response to that, I would appreciate it.

Senator STAFFORD. All right.

[The information requested follows:]

Question: What is production capacity of CFC-22 and how rapidly could it be expanded.

Answer: CFCs are co-produced in integrated production facilities. In 1985 U.S. production was reported by the U.S. ITC as:

Chemical:	*Million pounds*
CFC-11	176
CFC-12	302
CFC-22	235

Some U.S. CFC plants were specifically designed to produce any of these CFCs and CFC production is commonly varied according to market demand. Many CFC-11 and CFC-12 production facilities can be quickly converted to CFC-22 production, though at somewhat lower capacity. New CFC-22 plants can be built in 2 years or less after siting and permitting.

Question: Toxicity testing status for FC-134a.

Answer: E.I. DuPont De Nemours & Co. have reported the following tests and results:

Test	Result
ALC/LC50 (inhalation)	Low Order of Toxicity
Cardiac Sensitization	Weak Cardiac Sensitization
Subacute Inhalation	Low Order of Toxicity
Chronic Oral Study	Not a Carcinogen
In-vitro Mutagen	Not a Mutagen
Developmental Toxicity	Not a Hazard/Developmental Effects Only At High Concentrations (also toxic to mother at these very high concentrations)

The most important test that has not yet been reported is the two-year chronic inhalation study to determine toxicity and/or carcinogenic potential in one species (Rat or Mouse). This test takes 24 to 30 months once commenced. EPA does not know whether these (or other) toxicity tests are underway in the United States or elsewhere.

Mr. THOMAS. I must say that the issue of substitutes is a major issue in the overall time frame by which chemicals can be phased out. It is one that we have spent a considerable amount of time on.

I think that you have heard testimony from some of the people who participated with us on that issue.

Senator STAFFORD. We have, and we noted that there is some conflicting testimony here as to whether or not CFC 134A is in the progress of test, and if it is in the progress of test, and how far along it is, which would, of course, reflect on how long it will take. So an information that you can give us, we would appreciate.

Mr. THOMAS. I will give you a written response right away on this question.

Senator STAFFORD. Thank you very much.

Thank you very much, Mr. Chairman.

[The information requested follows:]

Question: Are FC-134a product application tests underway?

Answer: Small quantities of this chemical are available for testing.

Senator BAUCUS. Thank you, Senator Stafford.

Senator Symms.

Senator SYMMS. Thank you very much, Mr. Chairman.

Gentlemen, thank you very much for your testimony. I appreciate what you have had to say this morning. As you heard from my opening statement, I have some concerns about employment and America's competitive position in relationship to what is being negotiated now.

Mr. Benedick, you are from the State Department and are involved in the negotiation, I understand. Is there any agreement being negotiated that would put United States companies at a distinct disadvantage with our competitors?

Ambassador BENEDICK. Senator, one of the main objectives of the United States' position in these negotiations has been to achieve an international agreement, which would not penalize U.S. industry, or which would make it unprofitable for other countries who did not join the agreement to try to gain at the expense of U.S. industry and U.S. employment.

It is for this reason that we have, in these negotiations, stressed the importance of trade provisions, to prevent countries that are not party, that eventually do not sign the protocol, from profiting at the expense of countries that do.

Senator SYMMS. I might ask Mr. Calio if he would comment on this also.

Does the Commerce Department feel comfortable that we are not negotiating something that will allow products that use CFCs manufactured in other countries come into the U.S. and be marketed causing job loss in the industry and loss of competitiveness?

Do you feel that we have a strong enough front to prevent that from happening?

Mr. CALIO. I am not really in a position to answer that, Senator Symms. The other part of the Commerce Department, the trade group, has been working with us, the science side, and they seem to have been reasonably comfortable with it.

Senator SYMMS. Would you like to comment on that, Mr. Thomas?

Mr. THOMAS. Senator, clearly, the issue you raise is an extremely important issue that we have worked on. I think that in the U.S. Government's process of developing a position, we have both gotten input from industry itself, domestically and internationally, but also from the Commerce Department on the trade side, as well as the U.S. Trade Representative's Office, to look at what kind of trade restrictions should be incorporated into a protocol for those non-participating countries. More importantly, looking at issues like what will be the freeze level, what will be the basis of the freeze level, what will be the CFCs and Halons incorporated in it, all from the point of view of what that means in the sense of not only impact on the stratosphere and prevention of depletion, but what does that mean in terms of the international competitiveness, so that we move forward to prevent that depletion, everybody is doing their fair share, their proper part of that, and somebody is not moving ahead competitively because they are participating.

Senator SYMMS. If we did impose a freeze, do you believe that industry would then develop a substitute that would be cost effective?

Mr. THOMAS. I believe there are three things that restrict the development of substitutes one, an economic incentive to develop that substitute, meaning that you have a market to sell; second, time, in order to get it developed, to go through the processes of developing it scientifically; and, three, the current state of knowledge technically as far as the process development is concerned.

Looking at information associated with those elements, substitutes can be developed. I think, in some cases, it is going to require a considerable amount of time, and that is what I have talked about time frames like 15 years for certain goals.

I think in other cases it will be cost effective internationally, but it will be more costly than, for instance, a particular chemical today. I think those costs will change as the substitute takes its place on the market. But I do think that those are all issues that are subject of both our review, and a subject of concern in developing this overall international agreement.

I would say, though, that I think those are also issues in addition to the concern about where do we have emissions and, therefore, how should we control CFFs to prevent depletion of the stratosphere. Those issues you mentioned are all very important reasons why we need an international agreement as opposed to going forward unilaterally.

Senator SYMMS. That is a concern I would have. If the American consumers are going to end up paying a much higher cost for all of the things where CFCs were used, then we have to be, sure that we come up with a plan that would not be unilateral, but international, and that is what your point is.

Mr. THOMAS. That is. We have a history. You know, we have taken unilateral action in the United States in the past on this issue, when we banned aerosols, and we saw virtually none of the rest of the world follow suit. We saw Canada and some of the Nordic countries follow suit, but we did not see the rest of the world follow suit.

We have seen the growth now overcome the benefit from that, and we see dramatic growth, particularly in other countries, of the use of chlorofluorocarbons. I think that what we need here, what we clearly need here, and I think the information, both scientific and economic information, supports it, is an international agreement.

Senator SYMMS. Thank you. My time is up.

Thank you, Mr. Chairman.

Senator BAUCUS. Thank you, Senator Symms.

Ambassador Benedick, could you help me out, and tell me what agencies within the Administration are involved in determining the U.S. position? What is our position as we negotiate an international agreement to freeze and work toward a phase down of CFCs? Would you just list the agencies involved?

Ambassador BENEDICK. I think that it might be better to submit that in writing, because I might leave one or two out.

Senator BAUCUS. What are the principal agencies involved?

Ambassador BENEDICK. As I mentioned, the U.S. Delegation in Geneva, two weeks ago, comprised representatives of the Environmental Protection Agency, the National Aeronautical and Space Administration, the National Oceanic and Atmospheric Administration, the U.S. Trade Representative, the Departments of Commerce, Energy, and Interior. I don't think that I have left anyone out. In addition, there are Washington agencies that were also involved.

Senator BAUCUS. How is the position determined? Do you all get together and argue; or does someone referee; or does someone have more votes than others; how does this all work out?

Ambassador BENEDICK. I think, as in any domestic or international process, there are interagency meetings, there are discussions and examination.

Senator BAUCUS. In this case, what happened?

Ambassador BENEDICK. That is exactly the way it proceeded. There were series of meetings and discussions, and analyses, both economic and scientific, based also on the information we are getting from other countries, positions of other countries.

Senator BAUCUS. Does each agency have one vote?

Ambassador BENEDICK. It is not taken by a vote.

Senator BAUCUS. Is there someone who is in charge, or is everybody of equal rank and stature, just depending on the force of the personality, or the person present, to determine what the position is, regardless of what office he or she may hold?

Ambassador BENEDICK. The meetings, depending on the subject of the meetings, were either chaired by myself or a State representative, or by an EPA representative, or some of the subgroups, for example, by the U.S. Trade Representative. This process of working together builds up the elements of the specific position.

As I indicated to you, the position was fundamentally unchanged. The elements were the same as what we started with in December. So it really a question of discussing tactics, and examining data.

Senator BAUCUS. Could you detail for me which agencies take the stronger view, and which agencies take the weaker view?

Ambassador BENEDICK. Mr. Chairman, I don't think that in the middle of negotiations that there is a useful purpose to be served by trying to second guess our tactics or to keep a day-to-day score card of what we may have given up, or what we may have won from the other parties.

Senator BAUCUS. I am sorry, Mr. Ambassador, I am not asking you for a score card. I am asking you which agencies have taken a stronger view, and which agencies have taken a weaker view just for our information.

Ambassador BENEDICK. I think that you would want to ask the agencies concerned what their particular positions are. I feel that we should be judged, Mr. Chairman, by the results. We should be judged by what the position was that we took to Geneva two weeks ago.

I think what is important in such a complex issue as this is what we come out with at the end. If we don't come out with a protocol that is satisfactory, we are going to have to answer to this Congress, and to the American public.

Senator BAUCUS. Secretary Calio, do you agree that the U.S. position, freeze the CFCs and Halons at the 1986 levels, working up to a 95 percent phase out, is the United States position?

Mr. CALIO. With consideration of science, yes, Senator.

Senator BAUCUS. So you do agree that this is the position?

Mr. CALIO. Yes, sir.

Senator BAUCUS. How quickly should we move toward 95 percent?

Mr. CALIO. That is unclear to me at this point in time, Senator.

Senator BAUCUS. I am asking for your position. What is your best position as to how quickly we should move toward a 95 percent reduction. What year should we move toward a 95 percent reduction, based upon the present science?

Mr. CALIO. I stated it very clearly, I thought, in terms of our agency. Reduction of global emissions within the next 10 years, based on our understanding of science, sufficient to limit the predicted long-term loss, say, by the Year 2050, of stratospheric ozone from vertical redistribution in column ozone in high latitudes. This is exactly our position.

Senator BAUCUS. My question, again, is, based upon your present understanding of the science, how quickly should the United States and the world move toward a 95 percent phase out?

Mr. CALIO. I am saying, significant reductions within the next 10 years.

Senator BAUCUS. Would the "significant"mean 95 percent?

Mr. CALIO. "Significant" means a larger number, yes.

Senator BAUCUS. Does it mean 95 percent?

Mr. CALIO. Not necessarily. Up to 95 percent, I think, is where we are.

Senator BAUCUS. So you are saying that in the next ten years, we should move toward up to 95 percent.

Let me state the question differently. Does Commerce have a view that is in any way different from EPA on the degree to which, how quickly, and how steadfastly we should move toward a phase out?

Mr. CALIO. I think I said, in my opening comments, that I agreed with the objectives stated by Mr. Thomas when he made his statement.

Senator BAUCUS. You agree with the position.

Mr. CALIO. That is right.

Senator BAUCUS. As well as the objectives.

Mr. CALIO. I agree with objectives, yes, sir.

Senator BAUCUS. Is there any area where you disagree?

Mr. CALIO. Mr. Thomas and I work together on a lot of projects. We don't necessarily see eye to eye on every subject.

Senator BAUCUS. I am talking about this one.

Mr. CALIO. We discuss different approaches to different things.

Senator BAUCUS. Is there any area where in any way you disagree with EPA on the degree to which we should move toward phasing out CFFs.

Mr. CALIO. No, sir.

Senator BAUCUS. Do you agree fully?

Mr. CALIO. That is right.

Senator BAUCUS. The Commerce Department agrees fully with the EPA's position.

Mr. CALIO. With the objective of moving toward 95 percent, yes, sir.

Senator BAUCUS. Thank you.

Senator Chafee.

Senator CHAFEE. Thank you, Mr. Chairman.

Mr. Calio, you talk about a global freeze at the bottom of page 3 of your testimony, "a true global freeze at current levels of production," and so forth, and yet you know that no true global freeze is contemplated. There is growth for developing countries. There are some countries that are not going to join. There are going to be some noncompliance within some countries that do join. So that a true global freeze just isn't in the cards; isn't that correct?

Mr. CALIO. I don't quite understand what you are driving at, Senator. Yes, I think that we can get to a true global freeze.

Senator CHAFEE. That is not our position in Geneva. That is not our position.

We allow, in our position, don't we, Mr. Benedick, that we expect that there will be some growth from undeveloped countries?

Ambassador BENEDICK. Yes, Senator, realistically that is the situation.

Senator CHAFEE. So my next question is this.

Mr. CALIO. Can I answer that second question, because I make a second statement. The second statement, sir, is that a reduction in global emissions, we say that there should be a reduction in global emissions, and that is how you can achieve a total global freeze.

Senator CHAFEE. I look on you as bringing the scientific contribution to this table and to the deliberations of our negotiators. You are the science end of things. Mr. Thomas has the science, too, but you have the largest group of scientists. They were here the other day.

Mr. CALIO. Yes, sir.

Senator CHAFEE. Dr. Solomon, and so forth.

Mr. CALIO. That is correct.

Senator CHAFEE. What do you say about the Wurzburg report that shows that even with a 50 percent reduction, it would amount to a 5 to 20 percent depletion of ozone? Doesn't that worry you?

Mr. CALIO. Yes. It gets back to your other question, and I would like to finish the answer to that, because all of these are wrapped together:

I handed you, and I hope that you have a summary report of the activities that NOAA carries out. Do you have a summary report in front of you, Senator?

Senator CHAFEE. It is attached to the back of your statement.

Mr. CALIO. Yes. Page 14 on that summary report.

Senator CHAFEE. Yes.

Mr. CALIO. What we have plotted there, based on a one-dimensional model, is the changes in the vertical distribution of ozone. I want to point out to you, you asked me how can I make a statement about the vertical distribution, if you look at that inner curve, what you see at altitudes around 40 kilometers, with a zero growth, because of the zero growth, because of the vertical distribution of the ozone, based on the theory today, you would project about a 25 percent reduction at that altitude.

If you look down at lower altitudes, around 15 kilometers, you see that you produce an increase in ozone of about 5 percent, do you see that on the right-hand side, these cause global climate changes.

Senator CHAFEE. We have to be careful here, though, because this redistribution has environmental consequences that we don't know about.

Mr. CALIO. That is correct. That is exactly correct, and that is what we are trying to get to, that they are producing global climate changes, we don't quite fully understand, and they are being produced by models that we haven't been able to completely validate yet. We know, from experiments, that this distribution does take place. We don't know the magnitude of it. But if you look at these models, you see what they predict.

Senator CHAFEE. My real problem, Mr. Calio, is that you carry the scientific end of the burden here, and I am not sure that you speak as forcefully about the concerns here as your scientists do.

We have had your scientists here and they painted a very grim picture of the future, if we continue the way we have been going. My deep concern is, as the person with the scientific input, I am not sure you are conveying that alarm either to us or to your fellow negotiators.

Mr. CALIO. Senator, I have talked to my scientists regularly. I understand exactly what they are doing and how they think. I have made two very strong statements here this morning of where we think things are, and that comes directly from our scientists. I don't put any twist or spin on it. It is what they have advised me to do, and that is the message that I carry forward.

I have interacted with State and EPA constantly on not only this project, but many others, and I usually try to convey what my scientific people tell me, and that is exactly where we are. You are moving toward a point about what is absolute certainty, and we don't have that certainty. We have several models that predict various changes. We are trying to measure those with long-term observations. We have done that for 25 years in one case, and 15 in another.

Senator CHAFEE. I just want to ask one more question, Mr. Calio. Don't you think that we have enough information based on science, which is the term that you use in your statement, to commit the U.S. to the position of automatic reductions?

Mr. **Calio**. I didn't say, "automatic reduction" in that statement. I think I said, "based on science."

Senator **Chafee**. My question to you is, should the U.S. position be to choose the option that goes to the automatic reductions?

Mr. **Calio**. From a scientific position, I can't take that position, because once you lock in an automatic reduction, you may find out that you haven't done enough, or you have done too much.

Senator **Chafee**. I think that there is little danger of our doing too much here.

Thank you, Mr. Chairman.

Senator **Baucus**. Thank you, Senator Chafee.

Senator Stafford.

Senator **Stafford**. Thank you, Mr. Chairman. I have just one more question.

I am going to direct this again to you, Lee. Several witnesses have said that there would be no benefit from unilateral action by the United States. It is my understanding, however, that if there is no change in present worldwide trends, ozone layer depletion in the Year 2075, which I may not be here then, will be 26 percent.

If the United States were to act unilaterally, even assuming that not one other country joined, which is, I suppose, an unrealistic assumption, but if the United States were to act unilaterally, the ozone depletion would be at about 10 percent in that year.

In other words, the U.S. could, by itself, reduce two-thirds of the ozone depletion. Would EPA's analysis agree with what I have just said?

Mr. **Thomas**. I don't know the answer to your specific number, Senator, but let me say that I am looking at, and our analysis is looking at two aspects of unilateral action, both from a risk based point of view, is it appropriate for the United States to take action, if nobody else is.

The United States took action, as I indicated, in the late 1970s because we reached that conclusion, and we may well reach that conclusion again.

Secondly, is it appropriate for the United States, when it takes action, to try to impose restrictions on other countries who don't follow suit, in other words, trade restrictions incorporated with our action.

Both of those aspects are things that we are looking at as far as action in the United States is concerned. I am committed to make a decision on those issues.

I will tell you that the more I have been involved in looking at this issue, the more I am involved in looking at where the real growth is in use of these chemicals, the more I am convinced that we need to move for a strong international agreement, and the more I am convinced that we are almost there, if we can maintain the momentum and the strength behind the negotiations that have been on-going now for a year.

Senator **Stafford**. Thank you.

Thank you, Mr. Chairman.

Senator **Chafee**. Thank you, gentlemen.

The chairman indicated that he will be right back from voting and that he had a couple of other questions. If you, gentlemen, would be good enough to just wait a few minutes, he will be right back, we will just recess now and everybody can relax.

[Recess.]

Senator BAUCUS. The subcommittees will come back to order.

I have a question for Ambassador Benedick, and then Mr. Thomas.

After we began to first meet in Geneva, and there was a second meeting in Vienna, and a third meeting back in Geneva, I am wondering what our U.S. team learned from other countries that would either add to firming up the resolve of the U.S. position of the freeze at 1986 levels, or what we might have learned from those countries which raised questions about the science, or the earlier EPA risk assessment, et cetera, that would cause our team to come up with a different position, that is, back off from its earlier position?

The basic question being, what did we learn from other countries that either strengthened the U.S. position or detracted from it and, on balance, what did we learn that led us to a conclusion as to what direction we might more prudently go?

Ambassador BENEDICK. Mr. Chairman, as Lee Thomas, Mr. Calio and I have said, there was no change. There was no backing off from the U.S. position. The elements of the position remain exactly as I described them in my oral statement, as well as in my written testimony.

Your question is well taken in the sense that there was a certain definite evolution on the part of other countries in the course of these three meetings.

It is fair to say that many of the other leading producing and consumer countries do not share the conviction that the state of the science leads inevitably to a phase out decision right now.

They are prepared to consider that as an eventual objective, once again, 95 percent not as a magic number, but as a direction, as a trend. But they are not prepared to write that into a protocol. This has remained fairly consistent from the very beginning.

I might say that this includes many of the countries that otherwise have been allied with the United States in pushing for what you and I, I think, would define as a strong protocol. It also includes, of course, the European Community and Japan.

Senator BAUCUS. My question really didn't go toward what their positions are, but my question really went toward what scientific evidence have they given you that would lead us, the American team, to change this direction, if at all, in any direction.

It is not their position, but it is more what scientific studies did they present to our team on the science that might change one way or the other?

Ambassador BENEDICK. I am sorry, Senator, I misunderstood your question.

As there has been no change in the U.S. position, then, what we have learned from them is not relevant in that sense. But what we have learned is where their negotiating position has changed, where it has evolved, and has moved closer to our own.

Senator BAUCUS. There is no science that you have learned from them that would, on a scientific basis, to cause us to reconsider or not to reconsider.

Have you learned any science from them, have they conducted any scientific studies, apart from their negotiating position?

I am not talking about the negotiating position. I am talking about the science that they may or may not have presented.

Ambassador **Benedick**. They have not come up with any new science that is not summarized in the report of the Wurtzburg meeting in Germany. In evaluating that science, because at some point science stops and policy begins, one has to then say, there is uncertainty in the risk assessment, and somewhere we are going to have to place our bets on these risks.

It is fair to say that a large number of other countries did not appraise the science as requiring that kind of a bet, neither in Geneva in December, nor in Vienna in February, nor again in Geneva two weeks ago, although they all, I think, without taking anything away from them, agreed that there is a serious threat, that actions have to be taken.

In that way, we have moved from what was originally the position of many of the countries that they just wanted to put a cap on capacity down to a freeze on production, which is a big step, now to a reduction from that production level, and then to a further reduction. That is very considerable progress that has been achieved during these negotiations.

As I say, a number of the other countries feel that the bands of the margin error on the science is such that they are not ready right now to sign to a fixed percentage for that ultimate goal, but they are willing to move in that direction.

Senator **Baucus**. Have any of those countries undertaken a study of the degree to which CFCs deplete stratospheric ozone in the same comprehensive way that the EPA has in this country?

Ambassador **Benedick**. I think that almost all of the countries have shared in the scientific assessments, the NASA WMO basic science, NOAA assessment which was published last year, and in the ensuing scientific discussions leading up to the Wurtzburg meeting.

Senator **Baucus**. In a sense, I can conclude, then, that no other country has any significant scientific study that contradicts that shared NOAA, NASA, EPA study?

Ambassador **Benedick**. That is correct.

Senator **Baucus**. Would a resolution passed by the Congress asking the United States to reaffirm its position of freeze at the 1986 levels, with a phase down to 95 percent help the negotiating posture?

Ambassador Benedick. Senator, I don't know the extent to which the United States congressional resolutions will influence the policy of other countries. To the extent that it is a reaffirmation of our current policy, as it has been expressed at this hearing by all of the witnesses, it certainly cannot hurt.

Senator **Baucus**. Do you think that it would help?

Ambassador **Benedick**. Yes, I do.

Senator **Baucus**. I have no further questions. Thank you all very, very much. We have taken most of your morning, and we appreciate it very much. Thank you.

Mr. **Thomas**. Thank you.

Senator BAUCUS. Our next panel will include Mr. Carl Jewell, Manager, Fire Suppression and Detection at Fenwal in Ashland, Massachusetts; Mr. Gary Taylor, Vice President of Rolf Jensen and Associates from Willowdale, Ontario; Mr. George Kerckhove, Group Executive Vice President of the Trane Company in LaCrosse, Wisconsin; Mr. John Pierce, President of John Pierce in Dallas-Fort Worth, Texas; and Dr. Fred Bowditch, Motor Vehicle Manufacturers Association of Washington, D.C.

Mr. Jewel, why don't you begin this panel?

I would invite the witnesses to summarize their testimony in 5 minutes. Thank you.

STATEMENT OF CARL JEWELL, MANAGER, FIRE SUPPRESSION AND DETECTION, FENWAL, INC.

Mr. JEWELL. Thank you, Mr. Chairman and members of the subcommittee.

My name is Carl Jewel. I am manager of Fire Suppression and Detection for Fenwal, Incorporated. We are manufacturers of Halon fire and explosion suppression systems and equipment.

I am also chairman of the Halon Fire Protection Task Group. This industry task group was formed last fall by three industry trade associations—the Fire Suppression Systems Association, the National Association of Fire Equipment Distributors, and the Fire Equipment Manufacturers Association. The purpose of the task group is to address the Halon ozone issue. We feel that it is important for you to understand the benefits of the uses of Halons, that there is no presently available substitutes for Halons, that action has already been taken to reduce emissions, and that an existing structure is already in place which can provide regulation and enforcement.

Halons fulfill a vital need in providing fire and explosion suppression for a broad range of uses in virtually every segment of commerce, industry, research, government, and military applications.

Halons are particularly suited for providing fire suppression in certain applications such as the protection of vital electronics, flammable liquids and gases, vital record storage, historical and cultural artifacts, aircraft engine and cargo compartment protection, and similar uses.

The unique and highly desirable fire extinguishing characteristics of Halons is not available with any other presently known fire extinguishing agents. In other words, we do not presently have any readily available substitutes.

Halons are essentially contained materials. That is, under normal conditions, the agent is released from its storage containers only when needed to extinguish fires. While the use of Halons is intended to provide containment, except for fire extinguishment, some emissions occur due to other causes. However, those emissions are controllable and, over time, can be significantly reduced. Voluntary action has already been taken by the fire protection community to address the ozone issue and implement significant emissions reductions.

We pledge our continuing support to achieve a balanced solution to minimize potential environmental damage, while fulfilling our primary role to limit direct and indirect losses caused by fires.

Fire protection is basically a regulated industry. Consensus standards governing the use of Halons are adopted by the National Fire Protection Association. These standards are, in turn, adopted on the local, State, and national level as building codes and regulations. Therefore, an existing structure is in place which can be utilized to control usage and emissions. We would urge that this existing regulatory and enforcement means be utilized to control unwanted emissions.

If legislative action is taken, let us make sure that it will have the desired effect. We must make sure that in solving one problem, we do not create others having equally or more serious environmental, social, or economic impact.

In conclusion, I would like to say that the objectives of the fire protection community are the protection of life and property from fires. As a community, we have taken positive action in response to the ozone issue, and we pledge our continuing cooperation and support in this effort.

We ask, in turn, that any legislative action take into account the value of continued fire protection measures and the life preserving, cultural, and economic benefits provided by Halons.

Thank you.

Senator BAUCUS. Thank you, Mr. Jewel.

Mr. Taylor.

STATEMENT OF GARY TAYLOR, VICE PRESIDENT, ROLF JENSEN AND ASSOCIATES, INC. AND CHAIRMAN, TECHNICAL COMMITTEE, NATIONAL FIRE PROTECTION ASSOCIATION

Mr. TAYLOR. Thank you, Mr. Chairman.

My name is Gary Taylor. I am Vice President of Rolf Jensen and Associates, and I am the Chairman of the National Fire Protection Association's Technical Committee that establishes the requirements for fire protection systems utilizing Halon 1301 and Halon 1211. In the interest of time, my oral testimony summarizes my complete statement, which I would like to submit for the record.

Senator BAUCUS. It will be included.

Mr. TAYLOR. Thank you.

The fire protection community is concerned with the possible environmental effect of the firefighting Halons. We are also concerned because the Halon fire extinguishants provide a unique tool in the protection of vital and important facilities. These Halons do not cause secondary damage and are people safe.

They are the only known extinguishants with these combined characteristics. They are used in occupied areas of great importance such as computer centers, strategic military electronics facilities, and repositories of significant cultural heritage. George Washington's Mount Vernon home is protected against fire by Halon 1301 systems, and Halon 1211 portable fire extinguishers. Fire protection Halons represent a high value use to our society.

The fire protection community was advised of growing evidence and concern regarding the possible environmental effects of the

Halons in September of last year. Since that time, we have taken several important actions.

To begin with, a statistical study was undertaken. The purpose was to quantify, by cause, emissions that have occurred. Our findings indicated that discharge testing of Halon 1301 systems was the greatest source of emissions. As a result, we have withdrawn proposed mandatory test requirements, and provided improved technical guidance to manufacturers, installers, users, and enforcement officials to evaluate reliable operation by non-destructive means.

We have provided speakers to trade association meetings and professional societies to advise members of the fire protection community of our concerns and actions. We have formed task groups, and have developed a long range plan to reduce emissions from other causes, and we are examining the ways and means to encourage even more comprehensive recycling of these agents at the end of useful equipment life.

The Halons provide standby fire protection, and as a result are primarily banked. Less than one third of annual U.S. domestic production is emitted.

We have advised over 38,000 members of the National Fire Protection Association of our concern and actions by making this issue the feature point of the May issue of our journal, the NFPA Fire Journal. We are presenting a major symposium to deal with this issue next Sunday in Cincinnati.

We have involved our academic associates at the Worcester Polytechnic Institute and the University of New Mexico to assist us in seeking solutions and undertake research. We have selectively advised other members of the fire protection community in Canada and around the world, and we will share our programs and technology with our colleagues around the world.

We have done this on a voluntary basis, and we have done it using volunteers. We think that it is an important issue, and we are here today to try and bring the news that we think our community is in a position to help in reducing the emissions of these agents. We are not only willing to do so, we have already started to take the actions to do it.

I thank you.

Senator BAUCUS. Thank you, Mr. Taylor.

Mr. Kerckhove.

STATEMENT OF GEORGE KERCKHOVE, GROUP EXECUTIVE AND VICE PRESIDENT, THE TRANE CO., ON BEHALF OF THE AIR CONDITIONING AND REFRIGERATION INSTITUTE

Mr. KERCKHOVE. Thank you, Mr. Chairman.

I am Vice President and Group Executive of the Trane Company, which is a major manufacturer of air conditioning equipment.

On behalf of ACRI, for which I speak, which represents nearly all of the U.S. central air conditioning and commercial refrigeration manufacturers, I welcome this opportunity to give testimony. I have submitted a detailed written statement for the record.

As we all know, air conditioning and refrigeration systems are vital to our health and welfare. The life blood of these systems are refrigerants known as CFCs. As a matter of interest, our industry uses only about 25 percent of all the CFCs that are currently produced in the United States.

CFCs have been refrigerants since the 1930s because of their proven safe, non-toxic, and energy efficient characteristics. CFC 22, which accounts for nearly 55 percent of the industry's use, is broadly used for air conditioning and heating of homes, apartments, and many smaller commercial buildings. CFCs 11, 12, and 113 are normally used for equipment in larger buildings, including hospitals, and commercial and industrial applications.

It has been suggested that the industry use substitute refrigerants. This may be possible and we encourage it, but it may be many years away, and let me explain.

The only new potential substitutes known are FC 134A and CFC 123. These potential refrigerants have not been tested adequately at this time for toxicity or for compatibility with refrigeration equipment and systems. No commercial process or plants exist to manufacture them. If they prove to be acceptable, chemical producers tell us that they may be available in commercial quantities in a period of five to ten years, and perhaps cost many times more than what current CFCs cost.

If the refrigerants are proven acceptable for use, the time required by our industry for equipment redesign and development, including field testing, is at least 6 years. After that, we have to add production tooling before we go on to full scale production.

While some design work can begin before full commercial quantities of refrigerants are available, I think that it is important to realize that it will take somewhere in the area of nine to eleven years from the point that we have initial test materials from the producers before we can be in full production with redesign using those materials. Of course, that schedule assumes that there are no obstacles encountered in any phase of that process.

As I said, at this time, we do have serious questions about some of the alternative refrigerants in the areas of reliability, safety, performance, and chemical/mechanical characteristics, as well as the interchangeability potential of existing installed equipment.

In addition, we do have some other concerns, and that is the reported incompatibility with lubricating oils that are part of these systems. Further, neither CFC 123 or 134A have completed long range toxicity tests.

Because of the very uncertain state of these alternatives, the rapid phase down schedules that have been called for in the current bills will create a major havoc for our industry if implemented. For example, S. 570 would essentially eliminate the manufacture of CFC 22 by 1995, and both bills significantly restrict production of CFCs by 1995.

We do agree, however, with the science community and EPA that CFC 22 should be regarded as part of the solution to this issue, because it only has about 1/18th of the ozone depletion potential of CFC 12. There are some systems currently using 12 that could potentially be redesigned to use CFC 22.

Up until now, we have been talking about new installations. There is an existing large inventory of equipment in the field that must be serviced using current CFC refrigerants. I am speaking here today of virtually every residential, commercial, and industrial building that is currently in place, or that would be constructed over the next ten-year time frame.

Most of these systems have useful lives from between 15 to 30 or more years. Sufficient amounts of CFC refrigerants must be available in the future to service these systems until they can, long term, eventually be replaced, using CFC 22 or any of the new substitutes.

However, neither bill addresses the situation adequately. They currently exclude any reference to commercial systems from limited service exceptions which are in the bill.

We urge you to consider the impact on society of rendering unusable this existing inventory where there is a substantial investment.

At the manufacturing level, we have taken a number of voluntary steps to prevent the escape of refrigerants in our facilities.

We have also taken steps to provide guidance in our installation and service instructions in the field. We will continue, on a voluntary basis, to explore ways to reduce emissions.

We support the international limit on the rate of growth of CFC emissions. We support the efforts of EPA and the State Department, working with UNEP, to achieve an international solution to the threat to the global atmosphere.

Any further unilateral U.S. regulations would provide only limited environmental protection since over two-thirds of the total CFC production is outside of the United States. Further, unilateral U.S. regulations will make us, in our industry, less competitive.

In summary, there are five points that I would like to make.

We have a firm conviction, first, that this is a global issue, and U.S. restrictions should be considered only as a part of an international agreement.

Second, any action must consider an extended time table of at least ten or eleven years before substitutes can begin to be used in our products. During this time, current production and supplies of CFCs must be maintained to prevent havoc.

Senator BAUCUS. Could you summarize your summary more quickly, please?

Mr. KERCKHOVE. One more point.

Any action must consider continued servicing of existing systems, and we want a full assessment of economics. Lastly, government action should totally exclude CFC 22.

Thank you.

Senator BAUCUS. Thank you, Mr. Kerckhove.

Mr. Pierce.

STATEMENT OF JON PIERCE, PRESIDENT, JON PIERCE, INC., ON BEHALF OF AIR CONDITIONING CONTRACTORS OF AMERICA

Mr. PIERCE. Mr. Chairman, my name is Jon Pierce. I live in the Dallas/Fort Worth area, and I have a company there, Jon Pierce Incorporated, of which I am the president and the owner. I am a mechanical engineer by degree. I have been in the business for 19 years.

Senator BAUCUS. What business is that?

Mr. PIERCE. Air conditioning contracting, service contracting.

I come here representing the Air Conditioning Contractors of America, and some 3,000 members that it has. I served as its president a few years back. I have also been involved in the CFC issue for some nine to ten years from that experience.

I, too, have a concern about what we are talking about today, and it is twofold, and that is the effect on the environment that we are discussing, and also the effect on the industry which I am a part of. It is a half million employees, and some 250 million consumers that we serve. I am in the last link of the chain, so to speak, of the distribution process in serving the end-user.

The science, in my opinion, is still somewhat grey. The Antarctica situation can either be dynamically caused or it could be chemically caused. It is still not certain as to what is happening there from previous testimony that you heard.

I think all of our goals, certainly the people that I represent and yours, too, I would think, would be that we want a good environment for the future, but we also want minimum dislocations of employees, companies, and certainly consumers, which you represent.

My firm is a small, typical service company. We have 15 employees. We maintain systems that use about 80,000 pounds of CFCs. We purchase annually about 8,000 pounds of CFCs, which half of that would be R-22, and a third of that would be like R-12, and the balance would be miscellaneous items.

The points I want to cover would be some of the facts, the impacts of emissions, elimination if R-11 and 12, and what the impact of limitation of production on small business might be.

In regard to emissions, it is a fact today that all CFC products, per se, are vented to the atmosphere as they are used in the air conditioning industry. Existing equipment that is in the field today does not accommodate a reclaim process, or a recovery process as manufactured.

There is no controlled means of disposal today in the United States, to my knowledge. In other words, if you had reused material that is contaminated in any way, it would shortly destroy any equipment that it was put back in, because it has to have certain quality standards. There is no return system in place today where I could actually recapture a drum of refrigerant, take it somewhere, and have it be disposed.

The future equipment design could and should accommodate some reclaim processes. It can. Most customers that I know probably would not retrofit existing equipment to accommodate recovery unless there was some economic benefit for them to do so.

Leaks are responsible for quite a bit of this emission to the atmosphere caused by vibration of equipment over long hours. An air conditioning unit runs as much in one year as a car does in its lifetime, so you are talking about a different animal from a vibration standpoint or mechanical standpoint.

I will say this. In my 19 years in this business, I have never had a customer tell me that I should not look for the leak, if I had a leak in his system. He has always told me to find the leak, and let's fix it, as opposed to let's don't find the leak, let's just come out every six months and add some new refrigerant, and then we will go on from there. Leak detection has improved substantially in the last 19 years. New equipment designs could accommodate better leak prevention.

We have taken steps in terms of education. My employees have seen the film about Antarctica. We have purchased a reclaim or a pump out unit where we reclaim refrigerants.

The elimination of R 11 and 12, and if you took them out, that would obviously cut back the worst of CFCs. Most 11 and 12 equipment in the field today cannot be converted to 22. Replacement equipment lead time, obviously, will take many years. A third of my business would be eliminated overnight if that were the case, and it would have substantial consumer impact.

Production limits might encourage reuse. You can't mix refrigerants and maintain integrity of the refrigerant. It might promote some hoarding to take place in the marketplace and cause dislocations.

Rationing, which caused quite a few dislocations in the energy crisis of 1974, and also in World War II, could turn CFCs into a speculative commodity, where you have a $20 price here and a $5 black market price. In other words, I am through, my company is out of business because I don't have the financial resources to deal with it.

My conclusion, we, in the industry, are people and humans on earth, and we respect the earth's environment and its purity. We feel like an orderly approach is needed, not one of bans, caps, artificial taxes, or rationing. We support ARI's policy statement.

In my lifetime, I have two examples that I want to give to you that I think will give you an encouraging approach.

First of all, in my lifetime, I have seen the cyclamates dealt with where I had a friend in the bottling business, and half of his business was in the diet soft drink. Cyclamates were banned, and with the substitute, saccharine, which was not as good, in less than six months he was economically destroyed. Cyclamates proved later on to be acceptable, and not carcinogenic as originally thought, but he couldn't go back and reconstruct his business.

Another success story, however, where the government has done an excellent job, in my opinion, has been in the area of going from an unwanted leaded gasoline to a wanted unleaded gasoline. It has been one of the better stories that has come down the pike in a long time. In 1975, the EPA said, you are going to make cars that use good gasoline, unleaded gasoline.

I will go into Case Two, in the case of EPA, in the gasoline situation.

Senator BAUCUS. Could you summarize?

Mr. PIERCE. Yes, sir, I am going to get there.

The positive benefits have been great by going to unleaded gasoline. There have been very, very small dislocations in the industry. The lead gasoline remains to be used in vehicles that exist today, but they are phasing out. All imports and all exports use unleaded gasoline.

My answer to the problem is to mandate equipment redesign on air conditioning and refrigeration that would be used for domestic use, and exported and imported requirements. Give them a certain number of years to do this.

Then all harmful CFCs will go away, and all good ones will be used. There will be a market for the refrigerant manufacturers to go after, and we feel like it is a win/win approach. We can have good CFCs and their benefits, and we can have a good environment without major disruption to the industry.

I thank you very much.

Senator BAUCUS. Thank you very much, Mr. Pierce.

Dr. Bowditch.

STATEMENT OF DR. FRED BOWDITCH, VICE PRESIDENT, TECHNICAL AFFAIRS, MOTOR VEHICLE MANUFACTURERS ASSOCIATION

Dr. BOWDITCH. Thank you, Mr. Chairman.

I am Vice President in charge of technical affairs for the Motor Vehicle Manufacturers Association. It is a trade association representing domestic manufacturers which produce 98 percent of all U.S. built motor vechicles.

The threatened depletion of the earth's stratospheric ozone layer does deserve serious attention in spite of the uncertainties remaining about the exact nature and extent of this threat and its potential impact on human health and the environment.

Furthermore, there is broad and growing recognition that ozone depletion must be viewed as a global problem requiring an international solution. With the U.S. accounting for an estimated 30 percent of the CFCs annually produced in the world, it is obvious that unilateral U.S. action alone cannot provide an effective remedy.

We are concerned with the present UNEP negotiations, which are proposing a possible 20 percent reduction by 1992, because the U.S. already has taken a major step toward reducing CFC emissions by banning their use in aerosol products. Any international agreement should recognize this fact, and credit the United States with the reductions achieved to date. Lack of such recognition will put present U.S. industries at a trade disadvantage.

As to motor vehicle usage, three suspected ozone depleting CFC compounds are presently used in the motor vehicle manufacturing process.

CFC 11 is used in a flexible foam blowing process to produce seat cushions and padding to improve occupant crash protection. Alternatives appear available.

CFC 113 is used as a cleaning solvent in degreasing parts in the manufacture of electronic components. Conservation practices greatly reduce emissions.

CFC 12 is used as a refrigerant in mobile air conditioning. In terms of usage, it is CFC 12 which is most important. It is estimated that almost 40 percent of the CFC 12 produced in the United States goes for servicing and charging mobile air conditioning. Of that amount, new vehicles account for only 25 percent of the CFC 12 used each year. The rest, or some 75 percent, is used to service existing vehicles. Any rollback of CFC production must, therefore, assure that there is an adequate amount available for servicing existing vehicles for a number of years into the future.

As to substitutes, there is no readily available alternative refrigerant to CFC 12 that can be used in today's automotive air conditioning systems. One of the most likely substitutes is the fluorocarbon FC 134a. This refrigerant has performance characteristics similar to CFC 12, but is not considered to deplete the ozone because it contains no chlorine. However, there are many unanswered questions that need to be resolved concerning its engineering performance, its safety, and toxicity, as well as its commercial manufacture in quantities sufficient to meet the current demands for CFC 12.

We have discussions underway with the EPA for joint government/industry research programs on this matter. Such research could help eliminate duplicative, costly research efforts and provide assurance that the results would be credible and available to others.

As to our lead time requirements, any new refrigerant requires careful assessment of environmental impact and engineering requirements relative to both its manufacture and its application. For example, for FC 134a, long term toxicity tests, which take from two to three years, must still be completed. Its thermophysical properties and its compatibility with system components, such as hose materials and lubricants, must be determined.

Assuming that FC 134a passes these tests, sufficient lead time must be provided to include development and establishment of a commercially viable manufacturing process for FC 134a, as well as placement of orders for equipment and facilities necessary for volume production of motor vehicle air conditioning systems.

This process is estimated to require from seven to eight years to complete. Some manufacturers believe that another two years may be required to incorporate these new systems into all assembly plant production lines across the United States.

Thank you, Mr. Chairman. I have filed a more complete statement for the record.

Senator BAUCUS. Thank you, Dr. Bowditch.

Generally, you are all saying that it makes sense to proceed prudently, cautiously, because, on the one hand, CFC emissions probably do have some adverse effect on stratospheric ozone, but on the other hand, because of your view that science is not certain, there are still some unanswered questions, and because of the cost of dislocation, that is, substituting different products, which have some unknown factors still, and also the cost to the end-users, whether it is purchasers of refrigerators, or manufacturers of refrigerators, or air conditioning systems, and so forth. The point is that we should not move too quickly here, not jump the gun.

I am wondering what your position would be if you were more convinced of the science, that is, if it were more clear in your mind that the present rate of emissions and future growth rate of CFC emissions in the world, in fact, relating to a quite significant increase in melanoma, damage to human immune systems, retina damage, adverse effect on crops, and other aquatic and biotic life in this country and the world. Would your views change; would you think that, yes, we have to move much more quickly?

I am wondering if you would have a different view if you were more convinced of the science.

Mr. KERCKHOVE. Mr. Chairman, I think that the answer to that lies in the acceleration of the research efforts to get substitute refrigerants to us as an industry, faster and more quickly than what the tentative time tables are that we are now looking at, because our process for redesigning equipment and looking at application substitutes has to start with knowledge of a proven substitute refrigerant of similar characteristics of the present CFCs. Whatever efforts can be brought to bear to accelerate R&D efforts on substitute would be a high priority.

Senator BAUCUS. Does anyone else have a view?

Dr. BOWDITCH. Yes, Mr. Chairman.

As you will note on the lead time charts that we have attached to our written statement, we believe that we know enough about 134a at this point that we are willing to start the development of our automotive air conditioning systems at the same time that these two to three year toxicity tests are underway, so that we will be doing both research and development at the same time. This was included in the seven to eight-year lead time estimate that I made.

Senator BAUCUS. Would you all agree that we should move much more quickly if you all thought that the science was more clear and more certain?

Mr. TAYLOR. From the standpoint of the fire protection community, although we recognize that there is doubt about the science, we have taken the action as if the science is absolutely certain. We have moved ahead.

Senator BAUCUS. Didn't I hear you say in your testimony that emissions are 30 percent?

Mr. TAYLOR. What I said was that out of the total amount of Halons that come in, less than one-third of them are emitted. The rest is going into banks. What we are trying to do is to drastically reduce that, the emissions that remain.

We recognize that we still have to put fires out, which is a source of emissions, but what we are trying to do is to stop the material being used for testing systems, from leaking.

Senator BAUCUS. I understand that, but I was wondering, if the science were more clear, you would also move quickly toward substitutes in addition to control systems.

Mr. TAYLOR. We don't have any substitutes.

Senator BAUCUS. What is the next best material that you can use?

Mr. TAYLOR. The only other clean agent that we have now is carbon dioxide, and the problem with carbon dioxide is that it is not compatible with people. We are going to kill the people in these areas if we discharge carbon dioxide, that is the spot that we are in.

Senator BAUCUS. That is a spot that I wouldn't want to be in.

Dr. BOWDITCH. Mr. Chairman, one of our longest lead time problems is that of servicing the existing population of air conditioning units in the 90 million cars that are out there today, and that is going to take something on the order of ten years. We would like to encourage the American consumer to trade his car more rapidly, but that seems to be about what it will take.

Senator BAUCUS. Dr. Bowditch, what auto companies are testing substitutes now?

Dr. BOWDITCH. Certainly the major members of our association, General Motors, Ford, and Chrysler. American Motors is to some degree so far as we are aware. We are not aware of all of our individual companies' plans in detail.

Senator BAUCUS. Is that extensive testing?

Dr. BOWDITCH. It varies somewhat.

Senator BAUCUS. Give me a rough sense of how much has been spent.

Dr. BOWDITCH. I don't know. I would have to get that figure for you. But as I indicated earlier, we have pretty well established that 134a will probably do the job; therefore, we are willing to start down the development trail before having all the answers. Please understand that spending millions of dollars is something we seldom do in the motor vehicle industry, until we know a system or component is proven.

Senator BAUCUS. So that I understand, is the problem with the air conditioning or the refrigeration more the additional cost of substitutes, or is it the greater problem the time it takes to develop, or is the greatest problem the retooling and redesign?

If you could rank those problems, which of those problems is the greatest?

Dr. BOWDITCH. It is the latter that is the largest problem. We need to find the substitute and then design a system.

Senator BAUCUS. It is not so much the cost. The cost isn't as much of a factor.

Dr. BOWDITCH. From what we understand, the cost will be 5 to 10 times what we are currently spending, but the refrigerant itself is not the major financial part of the total system.

Senator BAUCUS. Mr. Kerckhove.

Mr. KERCKHOVE. I think that the primary driving force here is really the availability of an approved substitute. There are cost impacts. There are going to be a lot of major investments made for tooling and redesign for new systems. The product costs associated with those new systems is going to increase. Refrigerants may be 2 to 3 percent of the product cost today, if you triple or quadruple the cost of the refrigerant, the cost of the product itself will go up perhaps 10 percent.

Looking at the materials, the R 11 material is a low pressure refrigerant, roughly at atmospheric pressures, and 22, which is thought of as a substitute, is 10 times that in terms of operating pressure. So you can't take a R 11 system, or a CFC 11 system, and think that you are just going to redesign it with a 22 or with a high pressure refrigerant.

It impacts everything, the casing, the compressor design, the couplings. The entire system goes up much more costly, so you might have a system cost impact of between 10 and 20 percent in order to accommodate what we are talking about here.

Senator BAUCUS. Thank you very much.

Senator Chafee.

Senator CHAFEE. Thank you.

Mr. Taylor, I have used on boats fire extinguishers with CO_2 in them.

Mr. TAYLOR. Yes, sir.

Senator CHAFEE. Yet, those have now been switched to Halon. Why can't we use CO_2 again? You said that it killed the people, it didn't kill the people on the boats.

Mr. **Taylor.** CO_2, for example, on a pleasure craft, for the machinery space, is probably a reasonable means of providing fire protection.

Senator **Chafee.** They were producing them and selling them, so I hope that it was reasonable.

Mr. **Taylor.** They were. I think that one of the things that happened, and there are certainly applications such as that where we can go back to carbon dioxide, but the feature of the Halon is that it doesn't take up much space, it was more compact, et cetera.

So that was a desirable type of feature that it was used in that case. If the area is not occupied and still requires a clean extinguishing agent, there is no reason why carbon dioxide cannot be substituted.

The problem we have had in the last 20 years has been a growing dependence on automation and computerization. These areas are occupied by people. The same thing in the strategic military facilities, for example, in command centers on major military programs, and electronic support. These are man-occupied areas with extremely high values and of extreme importance.

In that particular case, the discharge of a carbon dioxide system, in those manned facilities, becomes an extremely dangerous situation. We had a case in a military facility where there was a false discharge of Halon. There were 126 people in the facility at the time that the system discharged, if it had been carbon monoxide, most of them would be dead.

Senator **Chafee.** Here is the problem, gentlemen, that I think we face. Each of you say that you would like to move forward, but there has to be substitutes developed, and that is fair enough. No one argues with that. But without the pressure of somebody forcing the substitutes to be developed, there are not going to be substitutes developed. You move along in a leisurely fashion, making efforts.

I think that the automotive people are doing their best, but there is not that old incentive to get going as there would be if it were mandatory that you move out of these existing CFCs. Therefore, it is my view that absent such a forcing mechanism as the government saying, "by X year, you have got to be through," nothing is going to happen. Is that unfair?

Mr. **Kerckhove.** I think that some of the testimony that was given by the producers suggests that if there is a cap or a limitation of future growth of emissions and production of materials that that in itself would provide the incentive for the producers to accelerate, spend more time and effort on substitute R&D.

I think the position at ARI has been to support the action that is going forward on the international front. If we can come to a worldwide consensus and prototype where all industrialized nations of the world agree to put some limits on these materials, then I think that will greatly result in the incentives for the producers in the world to come up with the necessary approved substitutes.

Senator **Chafee.** My concern also is that there seems to be little incentive now for tightening up on the escaping of the existing CFCs in the atmosphere. I mean, the fact, I think you said, that 75 percent of the CFCs going into the cars that are currently operating, obviously, you are recharging these cars because it is escaping.

What can be done by mandating better gaskets, or replacement gaskets, or hoses, clamps, whatever it might be. What do you say to that, Dr. Bowditch?

Dr. BOWDITCH. Over the last 10 years, we have reduced the amount of CFC 12 that is used in an air conditioning system in an automobile by about a third. We use about two-and-a-half pounds now, and we were using about four pounds in the mid to late 1970s. We have cut our leakage by about 70 percent over those same years.

So we have gone down the road that you have mentioned. We have made things better. We are using less, therefore, obviously, there is less to lose out in the atmosphere ultimately. We have done quite a good job of controlling the leaks.

Senator CHAFEE. Why have you done that?

Dr. BOWDITCH. For two reasons. One, the consumer doesn't like it if he has to recharge his system after four or five years. Secondly, we have recognized this problem for quite a number of years.

Senator CHAFEE. Let me ask you this. Is the portion of the recharging a substantial part of the recharging cost, or is it the labor, the equipment, the time, and so forth?

What is the actual CFC itself, what portion of the expense? I don't have an air conditioner in my car, so I am innocent in these areas.

Dr. BOWDITCH. I would be delighted to help you, Senator, in arranging for a car that would have that equipment in it.

Senator CHAFEE. You are a superb salesman, Dr. Bowditch. This is the second pitch you have made on automobiles. But seriously, what does it cost to recharge and how much of that is the gas?

Dr. BOWDITCH. Very little is the price of the gas itself. You can buy it in the local auto parts store for just a few dollars. It is a can that contains roughly four pounds of CFC 12. The cost for having a system charged is something on the order of $20 to $30.

Senator CHAFEE. Let's say that it is $30, how much of that how much would be the gas?

Dr. BOWDITCH. The gas, I think, and I haven't checked prices recently, it would be a matter of perhaps three or four dollars at most for the refrigerant, or 10 percent of the total.

Senator CHAFEE. If you went to more expensive gas, it wouldn't affect the price of it very much, but again you would have to have better clamps if you went to the 134a.

Dr. BOWDITCH. The 134a is what we are looking at.

Senator CHAFEE. I would say this, Dr. Bowditch. Several witnesses have pressed for a credit to the U.S., as you did in your testimony, because we banned aerosols, the other countries haven't, so, therefore, we ought to get a credit for what we have done.

Did you use to sell cars?

Dr. BOWDITCH. No, sir.

Senator CHAFEE. It is a good pitch anyway, but it doesn't take into account the fact that we are the world's highest per capita users having done that. So asking us to get a credit for something we have done, when we are already the highest and continue to be the highest user despite that, is pressing it a little far. But let's not debate that now.

Thank you all very much. I appreciate your coming.

If the next panel would come forward. Mr. Ganser, Mr. Hipchen, Mr. Jelin, Mr. Levy, and Mr. Pavek.

If those leaving would do it quietly. Mr. Ganser, why don't you go ahead.

STATEMENT OF NEIL GANSER, PRESIDENT, NEIL GANSER, INC. ON BEHALF OF THE SOCIETY OF THE PLASTICS INDUSTRY, INC.

Mr. **Ganser**. Mr. Chairman, I am Neil Ganser, President of Neil Ganser, Incorporated, of Bozeman, Montana.

Senator **Chafee**. First, let me say that I am sure Senator Baucus is coming back, but I know that he would want me to extend a special welcome to a representative from his State.

Mr. **Ganser**. Thank you.

I am a contractor/producer of spray in place polyurethane foam insulation products. Mine is one of several segments of the plastics foam industry totally dependent upon chlorofluorocarbon chemicals.

I appreciate this opportunity to present the views of myself and the Society of the Plastics Industry, Incorporated. Our industry uses approximately 30 percent of the CFCs produced in the United States. It is very significant to note that 20 to 30 percent of the cost of our product is attributable to CFCs. Therefore, any congressional actions related to CFCs would have a major impact on our industry.

Regulation of CFCs would result in higher prices for more expensive substitutes. One of SPI's member companies has analyzed the impact of tripling the cost of the CFC blowing agents. The study concluded that 50 percent of the existing rigid polyurethane market would be lost. Further, the study concluded that substitutes would, in general, be more flammable and poorer insulators.

Some are suggesting that a fee or a tax, such as $5.00 per pound, be imposed on CFCs to provide additional incentives to CFC producers to develop substitutes. Such a fee would not just place us at a severe competitive disadvantage, but it would eliminate our businesses totally.

Foam plastic insulation products, including spray applied and rigid board stock polyurethane, or polyisocyanurate foam, phenolic foams, and extruded polystyrene foams, are used in building construction, both residential and commercial, in home and commercial refrigeration insulation, in refrigerated trucks and railcars, and for tank and pipe insulation.

Spray foam insulation is also used to insulate facilities built to store bulk food products, such as apples in Washington, potatoes in Montana, Idaho, Washington, and Wisconsin, and animal confinement buildings like turkey sheds in California, and hog sheds all over the country.

Also spray foam is increasingly being used to control infiltration of radon gas into buildings, and radiation encapsulation at government nuclear facilities.

To give you an idea of spray foam's versatility, in Montana alone, my crew may go from spraying a house cavity wall to a spray foam roofing job on a factory, to a walk-in freezer, to pouring taxidermy forms, to forms for iron foundry casting, to undercoating semi-tractor trailers for the Alaskan highway truckers, to filling buoys for marking river channels, foaming flotation insulation on civilian and military water craft, to an underground mine to stabilize rocks for mine personnel safety.

That crew can go from insulating an outdoor hot-tub to a mobile television control center for the Olympic Games, to an environmentally controlled Pioneers Museum, to digestor lids on wasterwater treatment plants, to a flower delivery truck, to a drinking water storage tank in Yellowstone Park, to seedling enclosures for the U.S. Forest Service.

Member of that crew carry their lunch daily in a small cooler insulated with polyurethane pour foam, as is their family picnic cooler, and the energy efficient hot water heater, refrigerator, and freezer in each of their homes.

CFCs are also used to make flexible polyurethane foam.

Senator **Chafee**. Be alert to your time, Mr. Ganser, because you don't have too much.

Mr. **Ganser**. Flexible polyurethane foam is used as the principal cushioning material in furniture and automobiles, bedding, carpet pads, textile laminates, and for packaging. Polyolefin foam, which is used for packaging sensitive electronic and military equipment, is also made using CFCs.

In the plastics industry, CFCs are used to make fluropolymers which are used in the electrical and electronics industry, and in processing equipment for non-stick coatings.

CFCs are used to make plastic foam insulation because they provide the highest levels of insulation efficiency per unit thickness for energy conservation. While CFC 11 and to a lesser extent 12 act as an expansion agent during the foam formation, its primary function is to remain in the foam as an insulating gas. CFCs have a very low thermal conductivity, which results in excellent resistance to heat transfer.

Before I proceed, I want to discuss the ozone depletion issue briefly. Given the concerns about ozone depletion, SPI agrees that some responsible international action is warranted, which will address environmental concerns, while limiting the disastrous effects we will face if extreme measures, like those proposed by Senate Bill 570 or 571 are adopted.

We feel strongly that given the universal nature of the suspected ozone depletion problem, the U.S. response to the concerns should not be unilateral.

Senator **Chafee**. I can only give you 30 seconds more, Mr. Ganser.

Mr. **Ganser**. If Senator Baucus's and Senator Chafee's legislation is enacted, I will be hurt severely, as will the rest of the plastics foam industry. The years of work of myself, my employees, and thousands of others will become worthless. These bills call for extreme action without paying heed to economic costs for small businesses.

I am not a scientist, nor in a position to judge the theories relating CFCs to ozone depletion, I am not eager to have the world's climate change unnaturally for I am also an environmentalist. I have always felt that my company contributed to a better environment, so I get very frustrated when I see the environmental benefits of our insulation products being ignored.

The high insulation value of CFC foam plastic insulation results in a dramatic conservation of energy. The use of these products reduces the need for combustion of fossil fuels like sulfur coal to provide energy, and thus helps limit environmental damage from such things as acid rain.

Energy conservation has been one of our goals for over a decade. Enactment of the two CFC bills that I have referred to would reverse that direction.

Senator BAUCUS. Mr. Ganser, in the good tradition of solid Western ways, would you shorten your testimony a little bit please?

Mr. GANSER. We travel rather slowly out there.

Senator BAUCUS. We have to show them here that we are also men of few words.

Mr. GANSER. In conclusion, economic disruption and dislocation in the plastics foam industry need not occur if industry is allowed sufficient time—seven to ten years—for the development of substitutes. We ask you to consider the significant value of our products and their contribution in making our lives more productive, efficient, and comfortable.

Lastly, we ask you to realize that the economic impact on our industry of your proposals could cause many of us to lose not only our jobs, but the investment of a lifetime.

Thank you.

Senator BAUCUS. Thank you very much, Mr. Ganser.

Mr. Hipchen, why don't you proceed.

STATEMENT OF DONALD E. HIPCHEN, VICE PRESIDENT, JIM WALTER CORP.

Mr. HIPCHEN. Thank you, Mr. Chairman.

I am Vice President of Research for Jim Walter Corporation, which is headquartered in Tampa, Florida. I appreciate the opportunity to be here this morning to speak on behalf of the CFC users in the rigid foam plastic insulation industry.

Incidentally, by education, I am a chemical engineer, and I have been involved in rigid foam plastic insulation technology for about 25 years.

My company is one of the nation's 200 largest industrial firms. We have annual sales of about $2.4 billion. We are the world's largest manufacturer of foam insulations, with annual sales of those products in excess of $200 million. Over 1,000 of our 18,000 corporate employees are directly involved in the foam business.

Looking at the total foam insulation industry, incidentally, that industry has approximately $2 billion in sales, and employs somewhere around 40,000 people.

Rigid foam insulations are not new products. The technology and the use of them has been developing for about 40 years in this country and around the world. They are, however, the state-of-the-art in insulation products and energy conservation. They have the highest known efficiency of any insulation. They are two to three times better than the more classical insulations such as wood fiber board or fiberglas.

Foam insulations are now used in half of all new houses, about two-thirds of all new commercial buildings, and almost half of all new farm buildings. They are used virtually exclusively in household refrigerators and freezers, and in commercial walk-in coolers, freezers, and warehouses, and in refrigerated trucks and railcars. They are also used on tanks, pipelines, ships, aircraft, automobiles, and so forth.

The light weight and strength of these products has permitted the use of lower cost structural materials in buildings, and also in refrigeration applications. This has contributed to increased cubic capacity. We all have that in our own refrigerator at home. It has contributed increased payloads in trucks and railcars.

These foam insulations presently use CFCs 11 and 12 as expansion agents. About 90 percent of the total amount of the CFCs used remains inside the foam, encapsulated as a gas in the foam cells, and this is what gives them their high insulating efficiency.

There are no commercially available substitutes for CFCs 11 and 12 which can be used in foam insulations at the present time. Some possible substitutes have been identified, and they have been discussed here this morning. But our best estimate is that it is going to take about five to ten years to prove their suitability, to evaluate the toxicity of the materials, and to build the plants to make them, and for our industry to convert over to those alternates if they do, in fact, prove satisfactory.

An important point here is if the availability of CFCs 11 and 12 is reduced below the present available levels through only a partial phase out, and before suitable alternates are available to us, the majority of foam insulation products, and particularly those that are used in construction, in buildings, are simply going to disappear from the marketplace, and 70 percent of foam insulations are used in construction. This is the most cost sensitive application for all uses of CFCs, and it is going to be the first application to disappear if CFCs are reduced in availability.

Incidentally, this is not going to be the case in Europe and Japan. Because of the unilateral action that we have taken in the United States on aerosols, the Europeans and the Japanese have this large bank of aerosol material to draw upon to keep their foams in manufacture and sale.

If foam insulations that are used in construction do disappear in the United States, and are replaced by the less efficient, more classical insulations, the economic effect on energy conservation and on cost of construction is going to be just staggering. If it is done unilaterally in the United States, without some sort of trade restriction, we think that it is quite possible that these products would be imported from Canada and Mexico in large quantities.

Gentlemen, we believe that the resolution of the potential ozone problem requires time. We need time for the ozone science to determine if there is a problem. If there is, we need time to develop optimum approaches to deal with it. We need time to complete development of alternates to present CFCs; or time to develop new, advanced alternates to our present insulation products and systems.

Incidentally, I have samples of these products here, if you would like to see them. I would be pleased to answer any questions that you have.

Senator BAUCUS. Thank you very much, Mr. Hipchen.
Mr. Jelin.

STATEMENT OF WILLIAM JELIN, PRESIDENT, N.R.G. BARRIERS

Mr. JELIN. Mr. Chairman, members of the committee: My name is William Jelin. I am President, Chief Executive Officer, and founder of N.R.G. Barriers.

My father and I started the company twelve years ago, after my tenure here in Washington at the Georgetown School of Foreign Service. We have one plant in Sanford, Maine, and I chose to testify at these hearings, rather than observing our first production run at our new factory in Hazelton, Pennsylvania.

I am here today representing only myself, my family, our 100 employees, and our scores of satisfied customers. We manufacture rigid board polyisocyanurate foam insulation. Our satisfied customers, who have enjoyed the energy saving and waterproofing benefits of our products live at 1600 Pennsylvania Avenue, and in the Federal Correction Prisons in Fort Leavenworth, Kansas, and Lewisburg, Pennsylvania.

In the past year, our product has been installed in over 35 States. We are the largest supplier specialty insulated panels for cathedral ceilings in churches. Our most popular product, nailboard, has been used to winterize the army barracks in Fort Monmouth and Fort Dix, New Jersey, and Fort Devins in Massachusetts. I am proud to say that we just got an order today, in Washington, for the Federal Reserve Building.

You have heard from the giants of the American chemical industry. I am here today because I want you to know what will happen to a small family-owned business if some of the drastic phase-out proposals are implemented.

Environmental sensitivity is an instinct as basic to my ideology as any political belief I could have. I have been a member, in my home State, of the New Jersey Environmental Lobby, the Sierra Club, and New England's Council on Environmental Quality.

I am very proud of the fact that my company manufactures the most thermally efficient insulation known to man. My company has made an important qualitative and quantitative contribution to America's efforts to reduce energy waste and to reduce its reliance on imported fossil fuels.

In fact, we derive all of our requirements from the B side of our formulation from recycled soft drink bottles, the disposal of which is one of the most pernicious environmental problems. Nevertheless, I understand that the very manufacture of our product may be an environmental problem.

Our product utilizes CFC 11 as a blowing agent in the manufacture of the plastic foam. The CFC gases are trapped in the tiny bubbles of the cellular plastic. It is the very low thermal conductivity of CFC 11 that creates the excellent insulation value of our product.

Anyone would be crazy not to advocate restrictions on a gas if it proves to be as harmful to the environment as some of the experts fear today. However, I am not here today to debate the scientific issues. I am not a chemist. My company is not big enough to engage in the kind of research and development which might find an answer to this problem. This brings me to the crux of my testimony.

You asked me, what am I doing about the problem. As a small businessman, I am not in a position to develop chemical substitutes for CFCs. Stated another way, I am really at the mercy of my suppliers to develop an economically viable substitute. If they don't develop such a substitute, and you do enact legislation similar to S. 570 or S. 571, I am just out of business.

As I understand it, there are substitute for CFCs in many of the other products, other than foam insulation. But in our foam insulation, the CFC is the essence of our product. To ban the fluorocarbons will put us out of business.

I honestly believe that some of the substitutes for the product that have been mentioned in the EPA draft documents are toxicologically and environmentally, and practical substitutes. Regardless, the EPA is saying to me, get out of your business, walk away from your $10 million investment, lay off your employees, tell the people who use your product to insulate 65 percent of the commercial buildings in this country, that the product is simply no longer available.

I would be happy to consult further with any members of the committee on this issue, and to discuss my small business person's perspective on this issue with members of the committee staff, if they wish. I intend to be a frequent visitor to Washington while this issue is being considered because our very existence depends on it.

Thank you very much for the opportunity to talk to the committee.

Senator **CHAFEE**. Thank you very much, Mr. Jelin. It is a good statement, and you have made some good points. Thank you.

Mr. Levy.

STATEMENT OF MICHAEL H. LEVY, MANAGER, ENVIRONMENTAL, LEGISLATIVE, AND REGULATORY AFFAIRS, MOBIL CHEMICAL CO.

Mr. **LEVY**. Thank you, Senator Chafee.

My name is Michael Levy, and I am the Manager of Environmental, Legislative, and Regulatory Affairs Mobil Chemical Company. We at Mobil appreciate the opportunity to present testimony on the subject of alternatives for the polystyrene extruded foam manufacturing industry.

Mobil Chemical is an operating division of the Mobil Corporation. We are the world's leading producer of disposable plastic packaging products. They range from plastic grocery sacks, trash bags, and items that we are concerned about here today—egg cartons, disposable dinnerware, and hinged lid containers.

We use extremely small quantities of CFCs in only a small amount of the foam products we manufacture. The reason that we use CFCs at all is that it does impart certain desirable features to some of our product lines. Mobil Chemical pioneered the technology using a lower cost hydrocarbon alternative to CFCs as a blowing agent, and this is isopentane. In addition, our company has an aggressive R&D program that has resulted in the use of a combination isopentane/carbon dioxide mixture that has further reduced even the hydrocarbon/isopentane emissions.

Without getting too technical, in order to make rigid foam, polystyrene has to be converted into a rigid material. This is done by mixing a blowing agent, which is what we are talking about here, with the resin to make the form.

I have brought some samples. Basically, this is what it looks like without the blowing agent. This is how it comes out with it. You are probably familiar with many of these products. I am talking about the packaging products.

We do have five plants nationwide that make these. We use three different blowing agents in these plants. We use some commercial CFC, we use isopentane, as I mentioned before, a hydrocarbon which has been linked to ozone in the lower atmosphere, and we use the mixture of isopentane and carbon dioxide.

In four of our five plants, less than 10 percent of the production is made using CFCs. In the fifth and smallest plant, which happens to be out in California, CFC is used in the entire plant because of EPA emission requirements due to meeting the ozone standard out there. We are right now attempting to work out an agreement with them so that we can shift back into some of the hydrocarbon non-CFC blowing agent material.

The quantities of blowing agents that I talked about, all of them, are extremely small. The amount of blowing agent used in the extruded polystyrene foam sheet is about 3 to 5 percent of the product weight. As was mentioned before, about half of the blowing agent ends up in the product itself. The resulting emissions to the air are at very low concentration and highly diluted.

The selection of a blowing agent is usually dependent upon the desired properties of the product that you want, and there are some technical criteria, such as vapor pressure, how it plasticizes the material. Cost and availability, too, are important, since this is a highly competitive industry.

Mobil Chemical has been able to get up to about a 25 percent reduction of isopentane using certain product lines that are made with an isopentane/carbon dioxide blend. Product quality considerations such as surface smoothness, and the ability to print on these that has been the obstacle to increasing even more replacement of isopentane with carbon dioxide.

By developing this kind of isopentane/carbon dioxide blend, we have significantly reduced isopentane emissions. We spent anywhere from $3 million to $4 million over the last ten years in R&D costs on it, and we think that it is a fairly good cost effective technology option to add on control technology, which we have had to install in some of our plants.

We are experimenting with a greater use of carbon dioxide in the blowing agent mixture, but, as I said before, we haven't found a way yet to maintain the same quality standards.

In summary, a ban on CFCs in this particular part of the plastics industry, the extruded polystyrene from sheet packaging industry, if applied across-the-board, would have a minimal impact on our particular polystyrene business. In the interest of doing what is effective to improve the environment, we are going to continue our

R&D efforts to see if we can further develop the use of non-polluting blowing agents.

Again, I thank you for the opportunity. I will be happy to answer any questions that you have.

Senator **Chafee**. Thank you very much, Mr. Levy.

Mr. Pavek.

STATEMENT OF RICHARD PAVEK, PRESIDENT TECH SPRAY

Mr. **Pavek**. I am Richard Pavek, and I am the President of Tech Spray. We are a small chemical manufacturer in Amarillo, Texas. We provide chemistry for the electronics industry.

My personal background was primarily in the electronics industry, in research, and maintenance and repair of electronic equipment, so that many of my comments today about the specific uses of CFCs in the field come from a practical hands-on perspective.

There are a number of products that currently are used in the electronics industry that provide considerable economic benefit. For example, most of us, at one time or another, I think, have had some piece of electronic equipment that would intermittently fail, which usually means that it fails at home, and when you get it to the technician it works. The technician says, well, I can't fix it until it fails.

The reason for most of these failures is what are called thermal intermittence, meaning that some resistance film, some condensor, the inside of some component fails with a thermal change. One way to repair a piece of equipment that intermittently fails is to selectively replace all of the components that could cause that particular type of problem. In most pieces of electronic equipment, or in many pieces, at least, this might be 30 or 40 different components.

Once an individual component is replaced, you would not know if you had cured it until you ran it for a day or two. This was the condition of the industry until about 25 years ago when people brought out—this was before my time in the industry—what are called chilling sprays, which are a refrigerant in an aerosol can. I might mention that the Environmental Protection Agency thought enough of this particular usage to exempt the electronics uses from the ban on fluorocarbons in aerosols.

The unit is run at the operating temperature, and the technician goes through the unit selectively, component by component, squirting it and chilling it, chilling only that component and not the other components, for a period of two or three seconds. When the component is found that is intermitting, it will fail. So that in ten or fifteen minutes, often less, you can find the cause of trouble in a major piece of equipment that might take you weeks to find the other way.

I really don't know how to compare cost effectiveness on this. The CFC products used, obviously, are not too terribly expensive. The amount of material that is used is a few cents. The technician's time is of the essence here, and when you are talking about something like 15 to 20 minutes as opposed to several days of repeated effort, going back to this equipment and see if it has failed, trying over, and over, and over again, there is an astronomical difference, but I can't tell you what it is because nobody troubleshoots that way anymore.

Another place where fluorocarbons are used that is quite important is in the cleaning of the electronic equipment. Here we have a particular problem due to the smallness of the electronic equipment. The limiting factor on how close you can place lines, or printed circuit wiring, the limiting factor is the surface tension of the cleaning material, which cleans between those lines, and that means cleaning after each of the manufacturing operations, cleaning the fluxes after the soldering operations for example.

A surface tension of less than 20 dynes per centimeter is necessary to get a line spacing of six mil on the board. If you use solutions other than CFC's, you are going to go to about 15 mil. What that means is that with larger pieces of equipment that are not critical, your stereo equipment, your television set, would be larger. You might not want it to be larger, but it isn't of particular vital significance.

But every piece of small sensitive electronic equipment, every piece of avionics gear in all airliners and all aircraft, every piece of military communications equipment, every super computer, most large business computers, use small line spacing. All of that equipment would have to be redesigned, and would be two-and-a-half to three times larger.

At this time, there are no substitutes known for the Freon 113, and there are none in sight. A company such as mine simply does not have the money, the amount of money necessary to research a product for that particular use. I would estimate the cost of research to be right around 15 times the gross income of my company, so it is a little difficult for me to support, and for my banker also.

Senator CHAFEE. All right, 15 more seconds.

Mr. PAVEK. That is enough. I have said what I came to say.

Senator CHAFEE. Thank you.

First, I thought that the point that Mr. Jelin made about putting pressure on his suppliers to produce substitutes was a good one. We have been in kind of a catch-22 situation here.

We had testimony yesterday from the big producers saying that there was no incentive for them to develop substitutes, or what substitutes they could develop, because they couldn't sell them to their purchasers because the price might well be greater and the purchasers, in most instances, don't have the research and development capability to produce substitutes themselves.

Mr. Levy gave some very interesting testimony, I thought. He indicated that you folks have developed substitutes for the CFC 12.

Mr. LEVY. This is just for the extruded polystyrene foam packaging industry.

Senator CHAFEE. My question was going to be whether that would extend to the rigid forms that the other gentlemen were discussing, Mr. Ganser and Mr. Hipchen.

Mr. LEVY. I think that their testimony supports that polyurethane can't use the same blowing agents that we do.

Senator CHAFEE. Which is the isopentane?

Mr. LEVY. Yes. Their products have a different function.

Senator CHAFEE. You are a big outfit, so presumably you can handle the greater risk that comes from isopentane. It is more volatile, isn't it, firewise. It is more dangerous firewise.

Mr. LEVY. Whenever you use a hydrocarbon, isopentane in this case, we have had to make investments in handling equipment, separating out pump rooms, and things like that. We have weighed these additional costs against the cost of the other alternatives, and in fact in some cases it is the cheaper way to go. For example, you use less of the isopentane in the product. You use a little bit more of the CFC to make the same product.

But there are tradeoffs, and the one big thing, though, is the fact that, again, we are in a catch-22 situation. A volatile organic compound (like isopentane) hydrocarbon is regulated under the ozone standard, and in those areas of the country that are not meeting this standard, we have to put in additional emission controls. Many of the government agencies had leaned toward a non-hydrocarbon (like CFCs) as an answer. Now that we are hearing about CFCs and the upper atmosphere, perhaps, there may be emission controls also required for CFCs as well.

Senator CHAFEE. You are talking about the low level ozone.

Mr. LEVY. Right, smog, and the fact that we have had to put in expensive control equipment to reduce our emissions to be able to use the hydrocarbons as blowing agents.

Senator CHAFEE. Do you use the hydrocarbons?

Mr. LEVY. Yes, predominantly.

Senator CHAFEE. That egg carton you have there, was it produced that way?

Mr. LEVY. Yes. Right here, this is one using the CFC, and this is one using a hydrocarbon. The blowing agent cost is not a significant part of making this foam product, and I think that this is something that needs to be understood. About 5 percent of the product is the blowing agent, whether it is the CFC or whatever.

Mr. GANSER. Excuse me, on that point, that is for his particular type of foam, that is true.

Mr. LEVY. Again, you have to be very specific. I am talking about the extruded polystyrene foam sheet and finished products.

Mr. GANSER. In our particular type of insulating foam, it is 20 to 30 percent of our product cost.

Senator CHAFEE. That is what I was curious about. Yours is a different type of foam.

Mr. LEVY. It is a different process, and it is a totally different industry. For packaging purposes, we get a lot more out of a small amount of blowing agent to actually blow the foam for this kind of thickness.

Senator CHAFEE. What percentage, if you would make a guess, of those plastic polystyrene dishes that you have there that fast food restaurants use, and egg cartons that supermarkets use, would be made with the isopentane, do you think, as opposed to the CFC?

Mr. LEVY. The data that I have, and the Society of Plastics Industry is a good source to verify it, shows approximately 60 to 65 percent of these materials are made with hydrocarbons today. There are many companies that use them. This would leave about 35 to 40 percent made out of CFCs. This would be meat trays, egg cartons, fast food dishes.

Senator CHAFEE. Is there change in that equation?

Mr. LEVY. Not too much. I might add, though, that this entire industry uses less than 1 percent of the total CFCs. It is a very small portion of total CFC usage.

Senator CHAFEE. Let me ask Mr. Hipchen a question. With the foam insulation that you were talking about, the CFCs are retained and they are kept locked in the foam, and that is what gives the foam its insulating properties. It is not a conductor. But the CFCs are kept locked up for only so long.

What happens in the situation when you have a building torn down, for example. To use your example, it is used for truck insulation?

Mr. HIPCHEN. That is one of the applications.

Senator CHAFEE. When a truck body is reinsulated, or disposed of, what happens then, it is just ripped out, or do you think that we should be requiring more careful removal of the CFCs just like we do with asbestos?

Mr. HIPCHEN. Let me address your question in a comprehensive fashion, if I can.

Yes, the CFCs are released from the foams, but we are talking probably hundreds of years in the case of polyurethane foams, or polyisocyanurate foams, and certainly 50 years in the case of polystyrene foams, if there is no destruction of the foam. Of course, many of the buildings where these materials are used will last 50 to 100 years or more.

If the foam is totally destroyed, the CFCs will be released to the atmosphere.

Senator CHAFEE. How would that happen? When you say that the foam would be totally destroyed, what would take place?

Mr. HIPCHEN. Not only would you have to remove it from a building, you would basically have to grind it up or totally crush it to get complete release of the CFC from the foam. If you merely tore out large chunks of it from a building, and sent it to a landfill, the vast majority of the CFCs that is in the cells would still stay there. Only where you have fractured an individual cell will you release the CFCs.

Senator CHAFEE. I know many of you have testified that these CFCs are not going to be released for many, many years, but in all fairness that doesn't give us too much comfort. It gives us cause to be fairly nervous, doesn't it, because no matter what we do to curb these, nonetheless they are going to continue to be released in years and years and years to come.

I am not expecting you to totally agree with me, but we have an awful problem here.

Mr. HIPCHEN. I understand the point that you are making. I think that there are actually two sides to that point. The fact that most of the use of CFCs in rigid foam is contained within the foam, and would not be released for many, many years, it is going to do one thing for us, it is going to buy us a lot more time to get the answer to the science of ozone, and take action that is corresponding to what the science shows. We are not immediately releasing that into the atmosphere.

I understand the circumstances referred to as the bank, and there is a bank being created.

Senator **Chafee**. Thank you all very much. Many of you, such as Mr. Ganser, come from a long distance. We appreciate your being here.

I congratulate Mr. Jelin for his environmental activities. I know the area you come from.

We will do the best we can in dealing with this very, very severe challenge.

[Whereupon, at 1:10 p.m., the subcommittees adjourned.]

[Statements submitted for the record follow:]

Albert Gore Jr.

Remarks of Albert Gore Jr.
to the Environment and Public Works Committee
May 14, 1987

Thank you, Mr. Chairman, for the opportunity to submit these remarks to the hearing record on stratospheric ozone depletion. I want to commend you, Mr. Chairman, and the Members of the Subcommittee on Hazardous Wastes and Toxic Substances and the Subcommittee on Environmental Protection for calling these hearing on one of the most serious long-term environmental problems facing the United States and the World.

Modern man has acquired the technology to catastrophically modify the fragile atmosphere of our planet. On Tuesday, the Subcommittee heard a united voice from scientists testifying that anthropogenic chemicals are threatening the ozone layer. This stratospheric ozone layer protects life on Earth from harmful ultraviolet radiation. Medical experts have testified that we can expect to see increases in skin cancers and cataracts, possible reductions in crop yields and other deleterious effects on the biosphere.

The chlorofluorocarbons, which are ozone depleters, are also greenhouse gases. The greenhouse effect is caused by the buildup of carbon dioxide and other trace gases which trap radiation, causing the atmosphere to heat up. If today's worst case scenarios become tomorrow's facts, we will then have only a few decades in which to ameliorate the impact--which could range from drought in the midwest to floods on the coast.

Yesterday the Subcommittee heard from chlorofluourocarbon manufacturers. I commend the industry on acknowledging that the world's ozone layer is at risk if we do nothing to curb the growth in emissions of these chemicals. However, a global production cap is not sufficient. The United States must negotiate a freeze in the production of ozone depleting chemicals, followed by a phaseout. I urge the industry to continue its work in developing chemical substitutes. In the short term we can reduce our use of chlorofluorocarbons by substituting uses. But in the long term, we need environmentally safe chemical substitutes to insure the protection of the stratospheric ozone layer.

I look forward to hearing the testimony of the representatives from the Environmental Protection Agency and the Department of State. I commend the EPA on the thorough study that they are doing on possible chemical and use substitutes for ozone depleting chemicals. This work lays a good foundation for understanding how rapidly we can reach reduced levels of depleters. I urge the State Department to use this information to negotiate for the greatest level of phaseout possible, rather than accepting a 20% reduction.

Ozone depletion and the greenhouse effect seem out of scale when compared to the sorts of problems our political system is used to confronting. However we have got to act now. When one jumps from the diagnosis of the problem to the prescription for solving the problem, some of the important solutions appear to be unimaginable. As policymakers, it is our responsibility to expand our imaginations to seek possible solutions to these great threats to our global environment.

Thank you, Mr. Chairman.

TESTIMONY OF
LEE M. THOMAS
ADMINISTRATOR
U. S. ENVIRONMENTAL PROTECTION AGENCY
BEFORE THE
SUBCOMMITTEE ON ENVIRONMENTAL PROTECTION
AND THE
SUBCOMMITTEE ON HAZARDOUS WASTE AND TOXIC SUBSTANCES
OF THE
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
U.S. SENATE

MAY 14, 1987

Good morning Mr. Chairman and members of the Subcommittee. I am pleased to be here to discuss with you my Agency's recent activities related to stratospheric ozone protection.

As I have stated on several occasions before yours and other subcommittees, I view our efforts related to stratospheric protection as critically important. I am pleased to report that we have made substantial progress in dealing with this issue and in developing safeguards against the human health and environmental risks that would occur if there were depletion of the ozone layer.

I want to use this opportunity to briefly describe what I think we have accomplished and where we hope to go from here. I want to focus on activities related to our risk assessment, to the international negotiations, and to our domestic regulatory process.

RISK ASSESSMENT

In late 1986 EPA staff prepared an extensive 5-volume risk assessment document which presented the current scientific understanding related to stratospheric ozone. The document discusses likely trends in trace gases that create or destroy ozone, their probable effect on current and future trends in ozone levels, and the health and environmental effects if ozone depletion occurs.

To review this document, EPA's Science Advisory Board assembled a special panel of experts chaired by Dr. Margaret Kripke. Since she has already testified at these hearings, I will only briefly touch on my understanding of the outcome of their review.

In general, the panel thought that EPA had done a "commendable job" of synthesizing the relevant scientific information. They supported the basic thrust of the document -- that large risks of depletion exist if CFC use continues and that such depletion could lead to increased exposure to UV-B radiation resulting in higher incidences of skin cancers and cataracts, changes in the immune system, changes in plants and aquatic organisms, weathering of materials, and increased formation of ground-level ozone. They also reported that more sophisticated models suggest greater depletion is likely at higher latitudes. At the same time, their report underscored that only limited research has been conducted on many of these effects and that in the areas other than skin cancers, it is impossible to quantify risks.

I am also aware of ongoing research which raises important questions concerning the magnitude of the problem. The risk assessment and the decisions made to date assume that not enough is now known about the cause of the Antarctic ozone hole to determine whether this phenomenon is the result of CFCs or whether it has implications for the rest of the globe. While these questions still remain, the early evidence from the National Antarctic Ozone Expedition appears to suggest that chlorine chemistry does play a role. This year's scientific expedition should continue to expand our understanding of the Antarctic ozone hole. Because the implications are still not well understood, the U.S. negotiating position is not based on this phenomenon.

INTERNATIONAL NEGOTIATIONS

Because of the global nature of this issue, EPA has made a considerable effort to support U.S. government activities related to obtaining an effective international agreement to protect the ozone layer. We have taken a leading role, along with NASA and NOAA, in assisting the Dept. of State in numerous meetings with scientists and policy-makers from other countries as part of our efforts to convey to them the seriousness of this issue.

Drawing extensively from the risk assessment and from cost impact studies being conducted by the Office of Air and Radiation, EPA was also instrumental in developing the U.S. negotiating position for the international meetings. This position called for a near term freeze of the fully halogenated chlorofluorocarbons and Halons, and a longer-term reduction of emissions of these chemicals of up to 95% linked to a periodic assessment based on scientific, economic and technical considerations.

This position has been a strong factor in moving other nations in the direction of an effective protocol. In fact, it now constitutes the basic framework for the protocol which is beginning to emerge from the negotiations.

In the last round of negotiations, the U.S. negotiating team explored with delegates of other countries a wide range of possible reduction measures based on the view that the rate and magnitude of such reductions were closely linked. Given the broad spectrum of views that existed among parties to the negotiations, we felt it important that the delegation have flexibility to explore possible control measures consistent with our basic objectives. Thus, the U.S. position allowed for exploration of a range of options consistent with the U.S. objectives.

These instructions were developed following an extensive series of briefings involving other interested Federal agencies. EPA actively participated in these briefings and along with others both within and outside government presented background materials and analysis related to this issue.

As you are aware, the text that emerged from the April negotiating session called for:

-- a freeze within 2 years,

-- a 20% reduction 2 years later, or 4 years after entry into force (EIF) of the protocol,

-- an additional 30% reduction (for a total of 50%) either 4 years later (6 years from EIF) but requiring a positive majority vote; or 6 years later (8 years from EIF), automatically, and

-- a final reduction to possibly include virtual elimination of the use of CFCs to be decided based on a vote of the parties.

The Administration is supportive of the Chairman's text that came out of the Geneva negotiating session. We have a process underway to review its components in order to determine the best way to achieve overall international reductions of these chemicals, as determined to be necessary by the increasing body of scientific information.

It is my feeling that some components of the reductions should be automatic. This will provide the certainty necessary for industry to move forward aggressively with the development of substitutes.

Ambassador Benedick will be providing you with a detailed description of the outcome of the last round of negotiations. I just want to emphasize that I believe that substantial progress has been achieved and that a strong agreement within the current timetable appears to be within our grasp. The text developed by the session chair is to be reviewed by each party to the negotiations and comment will be provided in a follow-on meeting. I believe that this process could result in an effective international agreement. I want to assure the members of this Subcommittee that we intend to actively pursue the successful completion of these negotiations and look for your support in accomplishing this goal in the coming months.

DOMESTIC REGULATORY ACTIVITIES

At the same time that we have been aggressively pursuing an international agreement, we have also been conducting a detailed review of domestic regulatory options. We are considering possible regulation in two contexts. Should a satisfactory international protocol be reached, regulation will be needed to implement it domestically; given the global nature of this issue, this certainly would be the preferred approach. Alternatively, in the event that the ongoing negotiations are not successful, we will consider acting either in conjunction with other "like-minded" nations or unilaterally. Let me add that if the latter action proves necessary, we would endeavor to adopt measures which could encourage other nations to join us in reducing their use of CFCs.

This week, EPA, in a joint motion with NRDC, asked the U.S. District Court for the District of Columbia to modify its order establishing a schedule for an EPA decision on further CFC regulation. Despite our best efforts, we have not completed our review of regulatory options. We did not anticipate the the level of complexity and breadth of analysis required and the substantial effort and time the international negotiations have entailed. We therefore asked the Court to allow us to delay that decision until December 1, 1987, and to postpone a final decision from November 1, 1987 to August 1, 1988.

The additional time will permit us to complete numerous detailed studies now underway that will provide additional information for analyzing these options. The extended time-frame also allows for the continuation of the international negotiations, which are now scheduled to conclude in September of this year, without any possible interference which might result from announcement of a U.S. domestic proposal. EPA and the Department of State agree that publication of a proposed EPA decision at this time would risk unsettling the negotiations at a critical juncture.

CONCLUSION

We have come a long way since last June when I first testified before this subcommittee on the issue of ozone depletion. Given the complex nature of this issue and the need to involve other nations of the world, I think that we have made substantial progress. If we succeed in bringing these efforts to fruition and obtain an effective agreement this September in Montreal, we will have demonstrated that nations working together can deal with the extremely difficult problem of global pollution, including emissions of ozone-depleting chemicals.

STATEMENT OF
AMBASSADOR RICHARD ELLIOT BENEDICK
DEPUTY ASSISTANT SECRETARY OF STATE
FOR ENVIRONMENT, HEALTH AND NATURAL RESOURCES
BEFORE THE SUBCOMMITTEES ON
HAZARDOUS WASTES AND TOXIC SUBSTANCES
AND ENVIRONMENTAL PROTECTION
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
U.S. SENATE

May 14, 1987

I am pleased to present the following report to this distinguished body on the status of international negotiations on a protocol to the Vienna Convention of 1985 on protection of the stratospheric ozone layer.

Since we last met, in January of this year, there has been significant progress during two further rounds of international negotiations, February 23-27 in Vienna and April 27-30 in Geneva. This progress has been the direct result of a carefully planned strategy of intergovernmental consultations and public information efforts undertaken by the United States Government, as well as an intensive interagency review, bringing to bear the expertise and perspectives of as many as 18 different United States agencies and departments on these complex scientific, economic, and policy issues.

In our international efforts, we have been able to influence both public awareness and governmental policies, with direct implications for the negotiations. Domestically, the interagency process has refined and strengthened the analytical and policy underpinnings for the U.S. position, and has reinforced our belief that the general principles and approach which the United States Government has consistently advanced in the negotiations remain valid in the face of the risks from ultraviolet radiation.

The breadth and the intensity of the interagency deliberations is a testimony to the importance of the ozone issue and the seriousness accorded to it by the Administration. Just last Friday, Secretary of State Shultz, in a personal message to top-level U.S. executives on the occasion of the presentation of the World Environment Center's Gold Medal to the DuPont Company, stressed the importance of the international effort to control emissions of chemicals which harm the ozone layer. And earlier this year, Deputy Secretary John Whitehead emphasized to Dr. Mostafa Tolba, Executive Director of the United Nations Environment Program, the U.S. view that ozone is the highest current priority on the global environmental agenda, and he urged Dr. Tolba's personal involvement in the international negotiations.

I am pleased to report that, under Dr. Tolba's extraordinarily vigorous and effective leadership in Geneva last month, a significant convergence of hitherto widely varying viewpoints occurred on many of the critical elements of the protocol. Nevertheless, in important respects, there are still major differences separating the United States from the European Communities, Japan, and the Soviet Union. It is clear that further negotiations will be difficult.

On the particularly contentious issues of chemical coverage and stringency and timing of reductions, Dr. Tolba has crafted, with the aid of key delegation heads, a "chairman's text." There was general agreement among delegations that this text, although still subject to careful review by all participants, nevertheless begins to resemble in broad structure what an eventual control article -- the heart of the protocol -- might look like.

The Chairman's draft provides for:

(a) A freeze on CFC's 11, 12, 113, 114 and 115 at 1986 levels within two years of the protocol's entry into force (EIF). (Dr. Tolba strongly urged that the protocol be ratified by 1988, so that the freeze would be in effect in 1990.)

(b) A 20 percent reduction two years later, or four years after EIF.

(c) A further reduction of 30 percent (for a total cut of 50 percent from 1986 levels), for which two options were provided: (1) six years after EIF if a majority vote of the parties so decides, or (2) eight years after EIF unless a two-thirds vote of the parties otherwise decides. Either vote would be based on a prior scientific/technical/economic assessment.

(d) Future actions, including further reductions with the objective of eventual elimination of these substances, to be decided by the parties based on periodic scientific/technical/economic assessments.

There was widespread informal consensus that Halons 1211 and 1301 could be included in the protocol following expected action next month by the UNEP Governing Council to explicitly add these substances to the mandate of the international negotiations.

The scientific working group at Geneva also made progress, producing a report which supported the need for the protocol to cover all fully halogenated compounds, and confirming that reduction steps beyond a freeze are necessary in order to prevent long-term ozone depletion.

More negotiations will be needed on the control article, and considerable work remains to be done on provisions concerning trade between parties and nonparties, the definition of production/emissions/consumption, and treatment of developing countries.

We will be working on these issues in the coming weeks, both internally and in informal international consultations. The formal negotiations are currently scheduled to resume in Montreal, Canada, September 8-11, followed by a Diplomatic Conference to sign the protocol September 14-16.

In conclusion, the United States Government remains determined to arrive expeditiously at an effective international protocol which will both protect the ozone layer and prevent undue disruption to our economy -- a protocol which will include the maximum possible number of participating states, but one which will also make it unprofitable for those countries which do not accept their share of responsibility.

TESTIMONY OF
ANTHONY J. CALIO
UNDER SECRETARY FOR OCEANS AND ATMOSPHERE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

BEFORE THE
SUBCOMMITTEE ON ENVIRONMENTAL POLLUTION
AND THE
SUBCOMMITTEE ON HAZARDOUS WASTES AND TOXIC SUBSTANCES
OF THE
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
UNITED STATES SENATE

MAY 14, 1987

Mr. Chairman and Members of the Subcommittees:

The National Oceanic and Atmospheric Administration (NOAA) is focusing a substantial part of its mission-related environmental monitoring and research on atmospheric ozone. Our investigations are concentrated on global, as well as Antarctic stratospheric ozone depletion and tropospheric ozone.

For the purposes of today's discussion, my testimony will highlight the current understanding of atmospheric chemistry and dynamics and the appropriate role science must play in the formation of public policy. As part of my statement, I am providing a summary of NOAA's current and planned research efforts which, coupled with the testimony given by Drs. Susan Solomon and Adrian Tuck earlier in the week, will give the Subcommittees a good overview of NOAA's atmospheric science and research activities.

From a scientific perspective, any proposed regulatory policy should consider all of the fully halogenated chlorofluorocarbons (CFC's) and Halons, which are characterized by high ozone depleting potentials and long lifetimes, as a group. Consideration also should be given to the atmospheric growth rates of other trace gases, such as carbon dioxide, methane and nitrous oxide, which can influence the response of stratospheric ozone to CFC and Halon emissions.

The current understanding of stratospheric chemistry and dynamics predicts that the total column amount, as well as other redistributions of atmospheric ozone, respond to the total chlorine and bromine loadings of the stratosphere.

Current model predictions for emission-growth scenarios show global column ozone losses within the next 75 years to be larger than or equal to observed natural long-term variability (about 3%). Most atmospheric scientists believe that if the current growth rates of chlorine-and bromine-containing compounds continue unabated indefinitely, then it is likely that these ozone depletions will occur. They also believe that even with a global freeze, a 20-25% depletion of upper stratospheric ozone is likely to occur within the next 75 years, which could influence global climate.

In terms of ozone-trends observations, there is no compelling evidence in the existing groundbased and satellite data sets of a chlorine-induced ozone depletion. Inconsistencies in the data sets and the possibility of instrumental artifacts have divided the atmospheric science community as to the reality of any human-caused losses of global column ozone. NOAA is participating in a reassessment of these data sets with plans to report the results in the fall.

Scientific discoveries continue to be made and concentrated efforts to improve the understanding of what has been discovered advance the state of knowledge on an almost daily basis. In order to have a sound policy, a constant reassessment of our knowledge is absolutely necessary. Policy cannot be divorced from the science. NOAA participates in the current international negotiations of a CFC/Halon protocol and will strive to provide the most complete scientific advice needed to base these negotiations on the current understanding of atmospheric circulation and chemistry.

NOAA, based on the current understanding of the science, supports:

o a freeze, a true global freeze, at current levels of production, on all fully halogenated CFC's and Halons.

Such a freeze is predicted to limit the global average column-ozone depletion to 1-2%, which is on the scale of natural variation.

- o a reduction in global emissions, within the next ten years, based on our understanding of the science, sufficient to limit the predicted long-term loss, in 2050, of stratospheric ozone from vertical redistribution and column ozone at high latitudes.

NOAA will continue its vigorous scientific research in coordination with other agencies to address the processes that influence atmospheric ozone. The research and monitoring activities NOAA is undertaking goes forward with outstanding cooperation and collaboration with other agencies. The scientists participating in these efforts are first rate. Any public policy which evolves must be based on their work; any international negotiating position must be predicated on the science.

Mr. Chairman, I would be pleased to answer any questions you or the Members of the Subcommittees may have.

STRATOSPHERIC OZONE:

NOAA'S CURRENT RESEARCH AND PLANS
AND A SUMMARY OF THE STATE OF SCIENCE

Prepared by: Dr. Daniel L. Albritton
Director
Aeronomy Laboratory
Environmental Research Laboratories
National Oceanic and Atmospheric Administration

[NOTE: The following has been excerpted from the above-named report. The complete report has been retained in committee files.]

SUMMARY

NOAA and its scientists believe that atmospheric ozone is central to the chemistry, climate, and habitability of the planet. Hence, they have committed a substantial fraction of their resources and time to observing, understanding, and predicting its atmospheric roles as they relate to the environmental issues that are being faced currently. The status of the atmospheric science and NOAA's research related to these issues can be summarized briefly as follows:

GLOBAL STRATOSPHERIC OZONE DEPLETION

Background:

- According to a hypothesis proposed in 1974, man-made chlorinated and brominated chemicals [including chlorofluorocarbons (CFC's) and Halons, which contain bromine] may be depleting the stratospheric ozone layer, which blocks harmful solar ultraviolet radiation.
- Anthropogenic emissions of chlorine and bromine greatly exceed natural emissions.
- The compounds involved have long (on the order of 100 years) atmospheric lifetimes.
- National public-policy discussions are focussing on the need for further emission regulations on these compounds, and international negotiations are also underway in that regard.

Theory:

- From a scientific perspective, any proposed regulatory policy should consider all of the fully halogenated CFC's and Halons, which are characterized by high ozone depleting potentials and long lifetimes, as a group for the purposes of regulation.
- Several chemical compounds that have low ozone depleting potentials may have significant value as possible future substitutes.
- The response of stratospheric ozone to CFC and Halon emissions is sensitive to the atmospheric growth rates of other trace gases, such as carbon dioxide, methane, and nitrous oxide, which are emitted from man-made and natural sources.
- The current understanding of stratospheric chemistry and dynamics predicts that the total column amount, as well as the vertical, latitudinal, and seasonal distributions of atmospheric ozone respond to the total chlorine and bromine loadings of the stratosphere.
- Although policy has not set a "tolerable" stratospheric ozone loss, model predictions for emission-growth scenarios show total column ozone losses larger than or equal to observed natural long-term variability (about 3%).

- Hence, a freeze of total chlorine and bromine emissions is consistent with limiting predicted perturbations in the global-average column ozone to magnitudes less than the natural variation.

- This prediction assumes continued current growth in carbon dioxide and methane. If less growth actually occurs, then more column ozone depletion is predicted; if more growth occurs, less column ozone depletion is predicted.

- Even with an emissions freeze for the CFC's and Halons, current theory predicts substantial losses of ozone at 40 km eventually, which may have climatic implications.

- The current understanding of the interaction of stratospheric circulation patterns and ozone-loss chemistry predicts that more column ozone loss will occur eventually at higher latitudes than at the equator.

- Hence, a significant decrease in total chlorine and bromine emissions is consistent with limiting predicted perturbations in the column ozone and local ozone at the high altitudes and high latitudes to magnitudes comparable to natural variation.

- From the standpoint of limiting the maximum concentrations of the long-lived CFC/Halon compounds in the stratosphere, emission-rate reductions done earlier need not be as severe as those done much later.

- All of the above ozone responses are predictions made by atmospheric models that are based on the current understanding of the relevant atmospheric processes. While these models indeed simulate much of the present atmosphere fairly well, they are not perfect, which does place some limitations on their predictive abilities.

- Based on the present understanding, however, most atmospheric scientists believe that if the present growth rates of chlorine- and bromine-containing compounds continue unabated indefinitely, then it is highly likely that significant ozone depletions will occur eventually, particularly at the higher altitudes and latitudes.

- NOAA research will continue to focus on reducing the uncertainties in the predictions of stratospheric ozone perturbations. Specifically, the near-term efforts will be to:
  - measure, in collaboration with NASA, the abundance of stratospheric reactive nitrogen, which is an important parameter in ozone chemistry,
  - monitor the atmospheric concentrations of the the fast-growing new chlorinated and brominated compounds,
  - construct theoretical models that accurately simulate the smaller-scale ozone-related circulation patterns, and
  - develop an improved theoretical treatment of radiation transfer in the atmosphere and test it against vertical-distribution radiation measurements.

Trend Observations

- The ground-based Dobson spectrophotometer network provides a 25-year record of the variability of column ozone, which increased a few percent from 1960 to the 1970's and decreased afterwards. Analyses based on external ozone forcings, such as solar activity, find no fully convincing statistical evidence of a human-caused depletion in recent years, which is consistent with theoretical predictions of CFC effects to date.

- The Umkehr technique, which uses the Dobson instruments, yields a 15-year record of the vertical distribution of ozone. The data at 32-48 km show decreases over the past decade, but questions about artifacts due volcanic dust prevent a definitive statement regarding the significance of the trend.

- Unpublished results from the NASA SBUV satellite show distinct ozone decreases at 40 km, substantially larger than theoretical predictions. However, this analysis and the calibrations are undergoing intensive review, and the results are not yet accepted by the scientific community.

- Hence, there is at present no compelling evidence of a chlorine-induced ozone depletion in the existing ground-based and satellite data sets. However, inconsistencies between parts of the data sets and the possibility of instrumental artifacts have divided the atmospheric science community as to the reality of any human-caused losses of global ozone.

- NOAA ozone-trends research will continue to focus on improving the monitoring record. Specifically, it will:
  - continue participation in the Dobson and Umkehr networks and improvement and assessment of these methods,
  - collaborate in a re-assessment of the entire ozone data set and examine the significance of trends and the meaning of the inconsistences, with plans to report the results in the fall,
  - continue the recently begun NOAA SBUV satellite series to provide a global ozone record into the 1990's, and
  - participate in the planning of a state-of-the-art ground-based remote-sensing network that will detect stratospheric change and that will serve as calibration, backup, and extension of the satellite systems.

ANTARCTIC STRATOSPHERIC OZONE DEPLETION

Background

- Dobsons, satellites, and balloon-borne instruments have revealed growing, major (50%) ozone decreases over Antarctica in the austral spring season. The existence of this "ozone hole" is established beyond doubt.

- CFC/Halon-chemical, sunspot-induced chemical, and dynamical/climate-change theories have been postulated. The former evokes man-made perturbations; the latter two describe natural processes.

- The paucity of data at the time that these theories were proposed prevented the assessment of which one, ones, or if any are correct.

1986 Ground-based Expedition

- Last summer, NSF, NASA, NOAA, and the CMA supported a 20-investigator expedition to McMurdo Base, Antarctic, led by a NOAA scientist, to provide additional data on the "ozone hole".

- The balloon-borne and ground-based ozone results show a 40% loss, mostly in the lower stratosphere.

- Other measurements, also made by two different techniques, reveal that the abundance of the reactive chlorine compounds is highly elevated compared to other regions of the globe. Remaining uncertainties, however, prevent unequivocal identification of CFC/Halons as the cause of the ozone loss. The analysis of some remaining data is still in progress.

- Until the cause is established, the implications of the Antarctic ozone losses for global ozone cannot be addressed.

- Because the current theories of the "ozone hole" require the unique physical features of the region, the failure of the "standard" global ozone-depletion theories to predict its occurrence does not necessarily imply that these theories have major shortcomings regarding their predictions in other regions.

Plans for the 1987 Ground-based and Airborne Expeditions

- The fact that the chlorine chemistry in the Antarctic stratosphere is now known to be highly perturbed and the continuing need to define the dynamical processes make it mandatory to understand their roles in the "ozone hole" in much more detail. Hence, NOAA and other agencies plan a greatly expanded effort during 1987.

- First, NOAA scientists will take an improved instrument back to NSF's McMurdo Base and will also provide year-round ozonesonde balloon launches from the South Pole during 1987. Scientists from other agencies and institutions will make up an expanded ground-based research effort this summer.

- In addition, NOAA will join NASA, NSF, CMA, and university investigators in an aircraft expedition to probe the chemistry and dynamics at the stratospheric altitudes where the ozone loss is occurring. The flights will be based out of Punta Arenas, Chile.

- NOAA scientists will have five chemical instruments on board NASA's ER-2 and DC-8 aircraft, and one of these investigators will serve as mission scientist. These investigators will add to an instrument complement and meteorological support that are addressing very many of the key chemical constituents and physical parameters that are needed for testing the current theories.

ASSESSMENTS AND SCIENTIFIC ADVICE TO POLICY

- Scientific discoveries continue to be made (e.g., the "ozone hole") and understanding improves (e.g., the forthcoming trends re-evaluation). Hence, regular assessment of the state of knowledge is a key part of policy refinement. NOAA will continue to contribute in such reviews and assessments.
- In addition, NOAA will continue its participation in the current international negotiations of a CFC/Halon protocol and will strive to help provide the scientific advice needed to base these negotiations on the most-complete current understanding of atmospheric circulation and chemistry.

NFPA
"Moving Mankind Toward Safety From Fire"

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FIRE PROTECTION HALONS AND THE ENVIRONMENT -
A RESPONSE BY THE NATIONAL FIRE PROTECTION ASSOCIATION

Presented Before a Joint Hearing

of the

Senate Subcommittee on Hazardous Wastes and Toxic Substances
and the
Senate Subcommittee on Environmental Protection

May 14, 1987

Prepared by the
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The non-profit technical and educational organization: To promote the science and improve the methods of fire protection and prevention; to obtain and circulate information on these subjects and to secure the co-operation of its members and the public in establishing proper safeguards against loss of life and property by fire.

ABSTRACT

NFPA is a non-profit, independent membership organization with a firesafety mission of safeguarding man and his environment from the destructive effects of fire. In September 1987, NFPA became aware of the concerns over the link between the potential depletion of the earth's ozone layer and the emission of fire protection halons (Halon 1301 and 1211). NFPA is working in cooperation with fire protection professionals, the halon industry, and the U.S. Environmental Protection Agency to seek solutions to the concerns over the emission of fire protection halons and their possible effect on the environment.

In the past 15 years, halons have emerged as important fire protection agents in critical, high-value electronic environments for life safety, property protection, and the continuity of critical operations. Important applications include: telecommunications; banking; transportation; and the national defense. Halons have become extremely valuable to society because of these firesafety applications. In many applications, no other fire extinguishing agent is currently available as a substitute in meeting these firesafety objectives. Ultimately, we believe halons may well be one of the most essential uses considered under a national CFC production limit.

Fire protection halons are banked in systems to be employed when a fire is detected. Actually, only a small percentage of halons are emitted during fire fighting. Most halon emissions result from testing, maintenance, recharge, leakage, or training activities. We firmly believe these emissions can be controlled or eliminated.

Therefore, for the immediate future, users can reduce emissions significantly and maintain or improve fire protection through careful engineering analyses and research. The NFPA, working through its Technical Committee on Halogenated Fire Extinguishing Systems, has already taken important steps in the effort to reduce potential halon emissions, particularly with regard to system testing requirements.

For the future, there is a critical need to better understand halon emissions and to research ways to reduce halon emissions. There is also a critical need for education throughout the fire protection field to encourage halon emission controls. NFPA has established a research program to address these needs in cooperation with fire professionals, the U.S. Environmental Protection Agency, the halon industry, and the ultimate benefactors, namely, the users of halons themselves.

The NFPA is committed to spearheading an effort which will unite all concerned parties in adressing this important national issue.

INTRODUCTION AND BACKGROUND

A focal point of the fire protection community, the National Fire Protection Association (NFPA), is headquartered in Quincy, Massachusetts. Founded in 1896, the NFPA's mission is the safeguarding of man and his environment from the destructive effects of fire. The Association achieves this mission through an impressive array of scientific and engineering techniques as well as an expansive public education program. The NFPA is a non-profit, independent, 501(c)(3) organization with 38,000 voluntary members and an annual budget of 30 million dollars.

More specifically, NFPA conducts programs and projects in research and data analysis, the development of the National Fire Codes - internationally recognized firesafety codes and standards-public education, and technical advisory services. The Association also serves as a forum and clearinghouse for sharing ideas and technology.

The membership of the NFPA includes the fire service, health care, business and industry, insurers, federal, state and local government (including building officials), architects and engineers, fire equipment manufacturers and distributors, educational facilities, and trade and professional associations. Many NFPA members also participate in other independent fire protection-related societies or organizations which maintain a liaison with the Association. Examples are the International Association of Fire Chiefs, the Society of Fire Protection Engineers, and fire protection equipment organizations such as the National Association of Fire Equipment Distributors, (NAFED), the Fire Suppression Systems Association (FSSA) and the Fire Equipment Manufacturers Association (FEMA). These, too, are independent organizations.

NFPA has important links to the worldwide fire protection and fire research communities and is actively involved in such international organizations as: the Conference of Fire Protection Associations; the International Society of Fire Science; and the World Fire Statistics Centre. NFPA also works actively with international fire protection standards-making technical committees under the International Standards Organization.

Technical standards published by the NFPA are developed through a consensus process by volunteers and voted into use by the Association's members. These members represent a balance of interests including: manufacturers, installers, authorities having jurisdiction, users, insurance representatives and independent experts. The standards are adopted as regulations for enforcement by federal, state and local governments. In addition, these standards are adopted as ANSI standards by the American National Standards Institute.

A clearly unique feature of the fire protection community which is very important to this issue is that NFPA standards are widely adopted, used and enforced by various segments of governments. For instance, manufacturers, installers and users comply with these standards in their specific roles, while the standards are also used to enforce fire protection at all levels of government including: federal agencies such as the Occupational Safety and Health Administration; Federal Aviation Administration; US Coast Guard; state and local fire marshals; and state and local building officials. The standards are referenced by state and local building and fire codes and effectively serve as law. When referenced by the General Services Administration, Department of Defense or in private sector contract documents, they become mandatory requirements.

To promote coordination among firesafety standards and building codes, NFPA maintains liaison with the Council of American Building Officials in the area of standards development and application. This organization represents the building official at the national level and promotes coordination of the three model building code organizations in the U.S. NFPA halon fire protection standards are referenced in these codes and enforced.

Therefore, with NFPA standards, an established regulatory process and enforcement capability is already in place which offers the unique opportunity to achieve control of unwanted halon emissions. This is the most effective method of achieving the goals of the Congress, the U.S. Environmental Protection Agency, and the fire protection community.

NFPA HALON/OZONE RESEARCH PROGRAM

In response to the scientific evidence that chlorofluorocarbons, including fire protection halons could lead to future depletion of the stratospheric ozone layer, NFPA has established an important research program to address this environmental concern. Information and research are needed to help the fire protection community develop a reasonable response to the environmental concerns to reduce fire protection halon emissions, while maintaining an acceptable level of fire protection.

Only a small amount of halon emissions result from actual fire suppression. The majority of emissions are attributed to such activities as system testing or maintenance and fire suppression training. In light of the possible environmental impact of halon emissions, alternatives which minimize halon emissions while allowing them to fulfill their unique role in fire protection will be investigated.

The Program, proposed for an initial 18-month period (with an anticipated extension) includes several major components - Communications Strategy and Liaison, Data Collection and Analysis, and, Research on Halon Emission Reduction. A Project Advisory Committee, comprised of a balanced representation of individuals from the fire community, halon users, industry and the U. S. Environmental Protection Agency, will assist in setting program priorities and will review program results. NFPA will direct this effort in an independent, objective manner based on technical facts and findings developed under the proposed Program.

The benefits of this long-term NFPA Program are:

- It will provide support to Congress and EPA in addressing environmental concerns through statistics and research results regarding halon fire protection applications.
- Research results will assist in finding ways to reduce halon emissions while maintaining essential halon fire protection applications to ensure that firesafety objectives are achieved.
- Information generated by this Program will support code development activities of the NFPA Technical Committee on Halogenated Fire Extinguishing Systems.
- This program will produce information never before available regarding halon agent production, applications and emissions.

FIRE PROTECTION COMMUNITY ACCOMPLISHMENTS TO DATE

In response to notification by the U.S. Environmental Protection Agency regarding the possible effects of halon emissions on the ozone layer, the NFPA and the fire protection community took immediate steps to address this environmental issue. Numerous meetings were held involving EPA staff, NFPA, fire community and user representatives to gain an understanding of the environmental aspects and share ideas on ways to control halon emissions. EPA briefings were also held for NFPA technical committees including the Halogenated Fire Extinguishing Systems Committee and the Committee on Portable Fire Extinguishers. Dialogue on the issue was also established among the EPA, the fire community and environmental group representatives.

As a result of exchanges of information and sharing of ideas on the issue, several important steps have already been taken by the NFPA Standards Committees.

- The NFPA Halogenated Extinguishing Agent Systems Committee recently accepted a public comment to withdraw the proposed mandatory discharge test for inclusion in the 1987 Editions of NFPA Standard 12A, Halon 1301 Fire Extinguishing Systems, and NFPA Standard 12B, Halon 1211, Fire Extinguishing Systems.
- Testing and maintenance procedures in NFPA 12A have been revised to extend the time interval between required tests of system cylinders, thereby reducing emissions; and, halon will continue to be recovered.
- A subcommittee was formed to examine and review alternatives to the discharge test procedure. The use of calibrated door fans to check for enclosure leakage as well as the use of other test agents not posing a threat to the ozone layer are currently under study.

The above actions by the NFPA Committee dramatically show the Committee's concern regarding this issue. These actions also send a strong message that the fire protection community will take positive voluntary action combined with technologically sound approaches to best deal with this problem.

Other possible action to reduce halon emissions is being reviewed. A concern is the unwanted discharge of systems resulted from a number of causes such as tampering, installation, environmental causes and equipment-related malfunctions. Examples of positive preliminary measures designed to reduce these false discharges include providing isolation switches for use during maintenance procedures, and abort switches and time delays for all hazard areas - except those involving flammable liquids. The use of at least two types of detection devices which would respond to different fire stimuli, thus effecting automatic discharge, is also being considered. At present these recommendations are being developed as proposals for action by the appropriate NFPA technical committees.

In addition to the NFPA Halon/Ozone Program initiatives previously described, several communications and educational actions were launched.

- The May 1987, edition of Fire Journal includes feature articles outlining concerns and actions that are being taken on this issue.
- On May 17, the Sunday before the opening of NFPA's Annual Meeting, a symposium will be conducted to explain this issue to members of the fire protection community. Presentations will be made by EPA, NFPA Committee, halon industry, research community, and insurance engineering service organization representatives.
- During the Annual Meeting, the technical sessions of NFPA's Industrial Section will also deal with this issue.

Separate from NFPA initiatives, an ad-hoc Halon Fire Protection Task Group was formed by industry organizations such as the Fire Suppression Systems Association, the National Association of Fire Equipment Distributors and the Fire Equipment Manufacturers Association to take positive actions. This group has conducted statistical studies to determine usage and emission estimates. This data will help in determining priorities with regard to the most effective means to reduce overall emissions. This group is also developing procedures to further reduce leakage and other unnecessary emissions.

ESSENTIAL USES OF FIRE PROTECTION HALONS

Halon fire fighting agents effectively extinguish fires involving ordinary combustible materials, flammable liquids and gases as well as energized electrical equipment. In certain cases they are also used to make hazardous atmospheres inert. The halons are clean, residue-free agents which do not cause secondary damage and they present very low toxicity to humans. In fact, Halon 1301 is safe enough for use in occupied, protected spaces and discharge is allowed with people present. No other fire extinguishing agents with these combined capabilities are known at this time.

Because halons are very costly when compared to other fire extinguishing agents, they are used in applications where these combined properties are required. Typical halon applications would be computer facilities, telephone exchanges, petroleum pipeline pumping stations, military, vital electronic facilities and repositories of cultural and historically important properties.

For example, halons protect Mount Vernon - the home of George Washington, the Rosenback Museum - which houses Abraham Lincoln's notes used to prepare the Gettysburg Address, and, the Beineke Rare Book Library at Yale University. Major research laboratories such as Los Alamos Scientific Laboratories and the Johns Hopkins Applied Physics Laboratory, are protected by Halon 1301 systems and Halon 1211 portable fire extinguishers.

Halons represent a very high value use for society because of the fire protection mission applications. They protect not only our heritage, but the production capabilities which support our competitive position in world markets along with the research facilities which ensure our future advancement. Halons also contribute to our national security and military preparedness as well as the ability of our institutions to meet the needs of society.

It is of interest to note that a recent statistical study indicates that in 1985 more than 1200 fires in facilities such as these were extinguished by Halon 1301 systems with more than 20,000 fires extinguished by Halon 1211 portable fire extinguishers. Considering the critical importance of these types of protected facilities, the numbers reaffirm the vital role halon agents perform.

Due to their high cost, halons are not used for the protection of facilities typically subject to frequent fires. Therefore, most of the halon produced to date is presently stored or banked in containers to be released in the event of a fire.

While use of halons is normally intended to provide storage for the life of the fire protection system or device (except for fire use), some emissions do occur. And, because only a small percentage of halons emitted are due to fire fighting, the other unnecessary emissions are the target of emission control initiatives. The major causes of these emissions have been identified and are itemized below:

- Fixed Systems (primarily Halon 1301)
  - System testing
  - Unwanted (false) discharges
  - Emissions due to maintenance, recharging and leakage
- Portable and Manual Systems (primarily Halon 1211)
  - Training
  - Emissions due to maintenance, recharging and leakage
  - Discharge during testing

FUTURE ACTION AND NEEDS

As previously discussed, there is the need to reduce unnecessary halon emissions. Further, these emission controls are attainable. It is the intent of the fire protection community to primarily reduce emissions through programs to control and reduce emissions due to leakage, training, testing and unwanted discharges.

Initially it should be also recognized that the halon fire extinguishants are relatively expensive, especially when compared to other CFCs. Obvious financial benefits support existing procedures to control leakage and recover/recycle the halons. For example, the fire protection manufacturers and distributors presently recover vapor heels from shipping containers. Also, at the time of the internal inspection of portable fire extinguishers, a significant amount of Halon 1211 is recovered/recycled rather than vented into the atmosphere. Halon 1301 is recovered and recycled from obsolete or renovated systems or from storage containers requiring hydrostatic testing.

Several initiatives were taken to immediately seek halon emission reductions - particularly in the consensus standards process. NFPA has also taken steps to communicate this issue to all segments of the fire community and to users. These efforts initiated in 1986 will continue through 1987 and beyond. It is also expected that given funding support, research projects under the NFPA Halon/Ozone Program will be initiated in 1987 to identify and evaluate alternatives to full discharge testing of halon systems. Results will be shared with all parties concerned and initiatives taken through the NFPA standards process to impact unnecessary halon emissions.

Continued data collection analysis activities will be initiated in 1987 under the NFPA Halon/Ozone Program to develop better statistics regarding fire protection halon use and emissions. Analyses of these data will support improved decision analysis to target areas of greatest halon emission reductions. Statistics from this project can also track halon emissions over time for feedback to all concerned parties which will allow adjustments in initiatives to best achieve halon emission controls.

In addition to immediate communication and seminar efforts by NFPA, there is the need to communicate statistical and research results from the Halon/Ozone Program on a continuing basis. NFPA will continue to use its established publication and communication networks to do this in support of halon emission control objectives. Additionally, formal education and training products and workshops are being considered.

Some examples of procedural or training initiatives which could be accomplished by NFPA or the halon industry are:

- Produce a videotape presentation showing proper use, limitations, and techniques involved in fighting fires with extinguishers and hose lines discharging Halon 1211 and distribute it to appropriate audiences.

- Prepare an instruction manual covering installation, use, maintenance, and servicing of Halon extinguishers and systems for the industry and users.
- Prepare a standardized procedure and the appropriate apparatus for recharging, recovery and recycling of halons for application throughout industry.
- Devise a Quality Assurance Procedure to satisfy the certification laboratories while reducing the amount of agent released into the atmosphere during ongoing tests.

In addition to these future initiatives, the fire protection community has identified several needs in the areas of science and environmental research. Findings on the following will enhance the knowledge base and support future halon emission controls with positive impact on the environment:

- There is a need for a comprehensive measurement program to track Halon 1211 and 1301 in different parts of the world as well as at different altitudes to gain a greater understanding of how halons may interact in the ozone depletion processes.
- Additional studies are needed to determine the loss mechanism of halons in the lower atmosphere and to determine how this is influenced by solar activity at ground level.
- Studies should be implemented to determine how bromine-based gaseous products differ from chlorine-based products particularly with regard to potential ozone depletion mechanism.

CONCLUSIONS

Given the scientific findings regarding ozone depletion and fire protection halons, the fire community has taken steps in cooperation with the EPA and all interested parties to initiate immediate action to reduce halon emissions. The NFPA has established the Halon/Ozone Research Program and is committed to utilizing established capabilities including: communication networks, the consensus standards system, data analysis and research to address this environmental issue. We believe that the reduction of halon emissions can be achieved by the private sector through voluntary programs and through cooperation between the private sector and government agencies. The NFPA is committed to working with all concerned parties to respond to environmental concerns while achieving the reduction of halon emissions.

WRITTEN STATEMENT
OF
AIR-CONDITIONING AND REFRIGERATION INSTITUTE
ON
SUBSTITUTES FOR CHLOROFLUOROCARCARBONS
BEFORE
THE
SUBCOMMITTEE ON HAZARDOUS WASTES AND TOXIC SUBSTANCES
AND THE
SUBCOMMITTEE ON ENVIRONMENTAL PROTECTION
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
UNITED STATES SENATE
MAY 14, 1987

I am George H. Kerckhove, Vice President and Group Executive of the Commercial Systems Groups of the Trane Company. Trane is a major manufacturer of air conditioning equipment for residential, light commercial, commercial, institutional and industrial applications. We also manufacture equipment for food storage, transport and display. Our company employs 10,000 people in the United States. I am also a past Chairman of the Board of the Air-Conditioning and Refrigeration Institute (ARI), which I am privileged to represent here today. On behalf of ARI, I welcome the opportunity to testify at these hearings on the uses of CFCs in our industry, the status of alternatives to CFCs for our industry, and the impact of any future CFC regulations on our industry.

ARI is a national trade association representing approximately 170 manufacturers of air conditioning, heating and commercial refrigeration equipment. ARI's member companies account for over 95% of the central air conditioning and commercial refrigeration systems and components manufactured in the United States. Central air conditioners and heat pumps designed for use in residential and light commercial applications represent the largest volume of products and approximately one-half the product value manufactured by ARI member companies. Heavier commercial and industrial air conditioners, heat pumps and refrigeration equipment, ranging in type from factory assembled systems to those designed to specification for on-site assembly, comprise another significant percentage of the volume of products manufactured by ARI members. Other types of equipment manufactured by ARI member companies include rail and truck transport refrigeration units, water coolers and commercial ice makers. Although some ARI members manufacture room air conditioners, this equipment is not within ARI's product scope, nor are automobile air conditioners. Room air conditioners, refrigerators and refrigerator/freezers fall within the scope of the Association of Home Appliance Manufacturers.

The air conditioning, heating and refrigeration industry is a significant component in the U.S. economy. As of 1982, the latest year for which complete figures are currently available from the Bureau of the Census, the industry employed nearly 700,000 persons, including employees in the manufacturing, contracting, wholesaling and repairing ends of the business. Their salaries totaled over $13 billion. In 1982, the value of all air conditioning, heating and refrigeration equipment shipped by domestic manufacturers amounted to more than $12 billion. Including the sales and/or receipts of the contracting, wholesaling and repairing ends of the business including installation costs, the total value is increased to nearly $60 billion. Additionally, in 1982 the manufacturers spent approximately $330 million in capital investments, spread across more than 870 facilities nationally. Overall capital expenditures approached $1,000,000,000 over close to 70,000 establishments when contractors, wholesalers and repair shops involved in air conditioning, refrigeration and heating are included.

As important as the air conditioning and refrigeration industry is to the U.S. economy, its value goes far beyond mere dollars. Air conditioning and refrigeration equipment is vital to the health and welfare of the American public. Virtually all hospitals require air conditioning and refrigeration equipment to provide a comfortable environment, help reduce the spread of bacteria and infection, reduce dust and noise, and store vaccines, medicines and other products. In homes, and apartments air conditioning is important to good health by making residences cooler and cleaner. In 1984 71 percent of all new single family residences in the U.S., including 92 percent in the South, were built with central air conditioning. Refrigeration systems provide for safe and nutritious food and beverages during processing, transport, display and storage. Pharmaceuticals are also kept safe and viable through freezing, cooling and storage. Schools can provide for a better educational environment and year round classrooms through air conditioning.

Air conditioning and refrigeration systems are vital to modern industry and commerce as well. Equipment such as computers and computer rooms which often rely on cooling systems and air conditioned factories provide for increased productivity. The same is true for military equipment vital to the national defense. Most modern commercial buildings, industrial plants, hospitals, schools and other major structures are designed around air conditioning and would be uninhabitable at certain times of the year without it. In short, modern American society has been made possible in part by, and relies on, air conditioning and refrigeration equipment.

It is not exaggerating the fact to say that chlorofluorocarbons, which are used as refrigerants in virtually all air conditioning and refrigeration systems, represent the lifeblood of the air conditioning and refrigeration industry.

Without them, modern air conditioning and refrigeration equipment as we know it would simply not exist. CFCs have been used as refrigerants since the 1930s because they are non-flammable, non-corrosive, non-reactive, low in toxicity and efficient in heat absorption and transfer. While substitutes for the fully-halogenated CFCs are being researched, they are many years away from being approved for production. To date there have not been sufficient quantities available for full range testing, including toxicity, and equipment performance testing.

Because of the vital importance of chlorofluorocarbons to our industry, as well as to the welfare of the American public, we are naturally concerned about the direction that might be taken by any international or domestic regulation of CFCs. At the same time, we are also very concerned about the possibility that CFCs might weaken the global stratospheric ozone layer. For this reason, ARI has recently conducted an evaluation of the most current scientific and technical literature and has concluded that as a precautionary measure global limits on the growth of emissions of the fully-halogenated CFCs 11, 12 and 113 should be supported until further information can be obtained on the effects of chlorofluorocarbons on the upper atmosphere. ARI has also concluded that there is no need at this time to include any controls beyond CFCs 11, 12 and 113 or to include a production phase-down in the controls, believing that current science neither justifies nor requires such.

Although ARI fully supports certain international measures, the association believes that further unilateral actions by the U.S. to regulate CFCs would have only a minimal impact on the environment but could seriously harm the welfare of the American public, the U.S. manufacturers of air conditioning and refrigeration systems, and the international negotiations currently taking place. ARI believes that any domestic regulatory steps aimed at CFCs should be taken only to implement an international agreement supported by the other major industrial nations. In addition, ARI believes that certain unilateral (and for that matter, international) efforts to regulate CFCs, such as any aimed at curtailing the use of CFC-22, could prove disastrous for this industry, as well as the American public, and would provide little, if any, environmental benefit.

CURRENT INDUSTRY USE OF CFCs

The central air conditioning and commercial refrigeration industry relies to varying degrees on CFCs 11, 12, 22, 113, 114, 500 and 502 for use as refrigerants. Residential buildings, including apartments and single-family residences, almost exclusively use unitary air conditioners and heat pumps, which rely on CFC-22 as a refrigerant. Motels, nursing homes and similar buildings often use packaged terminal air conditioners and heat pumps, which also rely on CFC-22 as a refrigerant. The air conditioning systems in low-rise commercial buildings primarily use CFC-22 also. Larger buildings, such as hospitals, high-rise office buildings, larger hotels, large shopping malls and industrial complexes, are normally designed with large air conditioning systems, such as large tonnage centrifugal chillers, which predominantly use CFCs 11, 12 and 113. In the area of commercial refrigeration, CFCs 12, 22, 500 and 502 are used, among other things, to: refrigerate foods, pharmaceuticals and other products during transportation, storage and display; make ice; and cool water.

Specifically, the following categories of equipment, which are manufactured by ARI member companies, utilize the listed chlorofluorocarbons as refrigerants:

Equipment	CFC Type
Centrifugal Liquid Chillers	11, 12, 22, 113 & 114
Commercial Icemakers	12
Refrigeration Condensing Units	12, 22 & 502*
Drinking Water Coolers	12, 500**
Packaged Terminal Air Conditioners	22
Truck Refrigeration Units	12

Unit Coolers	12, 22 & 502*
Unitary Air Conditioners and Heat Pumps	22
Water Source Heat Pumps	22
Bus and rail air conditioning	12

* CFC-502 is a mixture of CFCs 22 and 115 (48.8%, 51.2%).

** CFC-500 is a mixture of CFC-12 and FC-152a (73.8%, 26.2%).

In 1985, the latest year for which complete figures are currently available, total U.S. CFC production equalled approximately 922 million pounds. Of this, approximately 225 million pounds, or 25%, was used by our industry. This figure includes the use of CFCs at all industry levels, not at just the point of manufacture. It does not include usage in automotive air conditioning or room air conditioners. In 1985, our industry used about 55% of all U.S. produced CFC 22, about 25% of CFC 12, and about 12% of CFC 11. Based on ARI estimates, the industry CFC usage by percentage in 1985 can be broken down as follows:

CFC Type	CFC use by per cent in central air conditioning
CFC-22	54.7%

CFC-11	8.4%
CFC-12	31.9%
CFC-113,114, 500, 502	< 5.0%

CFC-22

Before discussing any possible alternatives to existing chlorofluorocarbon refrigerants, it must be noted that ARI views CFC-22 as part of the solution to any environmental concerns associated with chlorofluorocarbons, not as a significant cause of any such concerns. This is because some systems currently using CFC-12 can be redesigned to use CFC-22. More importantly, CFC-22 has about 1/18th as much ozone depletion potential as CFC-12. Phrased differently, it takes 18 times as much CFC-22 as it does CFC-12 to reach the same ozone depletion potential.

Because it is significantly less ozone depleting than the fully-halogenated chlorofluorocarbons, CFC-22 has not become the focus of attention either by the U.S. Environmental Protection Agency (EPA) or the international community in the ongoing domestic and global debates concerning whether to regulate CFCs beyond the steps already taken. It should also be noted in passing that Professor Sherman F. Rowland, an original co-author of the ozone depletion theory and a leading advocate for further

CFC regulation, agrees that CFC-22 should be viewed as part of a solution to any concerns regarding chlorofluorocarbons.

Unfortunately, the Stratosphere Protection Act of 1987 (S. 570) and the Stratospheric Ozone and Climate Protection Act of 1987 (S. 571), recently introduced in the Senate, would impose punitive restrictions on the production of CFC-22. By 1995, S. 570 would essentially eliminate the manufacture of CFC-22 by phasing down its production to the level where its individual ozone depletion potential would be reduced by 95%, based on 1986 levels. The bill also brings CFC-22 within a 95% phase-down of total chlorofluorocarbon (and other regulated substances) ozone depletion potential by 1995, based on 1986 levels. S. 571 also significantly restricts production by bringing CFC-22 within this latter 95% phase-down of total CFC (and other regulated substances) ozone depletion potential by 1995.

The American public, as well as the air conditioning and refrigeration industry, could be seriously harmed by the regulation of CFC-22 because of its tremendous importance. As noted previously, approximately 55% of the CFCs used by the industry as a whole in 1985 were CFC-22. This use was, and is, for air conditioning and refrigeration applications vital to the health and welfare of the American public, and there are no non-chlorine alternatives to CFC-22, nor are any being studied which would not require a radical redesign of equipment presently using CFC-22. Certain vital air conditioning and refrigeration applications currently using CFC-12 might also be redesigned to use CFC-22 in the future since there are no non-chlorine substitutes currently available for CFC-12. Therefore, serious repercussions, with little environmental benefit, could be felt if CFC-22 were regulated.

One last point about CFC-22 deserves noting. The 100th Congress recently passed the National Appliance Energy Conservation Act of 1987 (Public Law 100-12), setting stringent minimum energy efficiency standards for residential air conditioners and heat pumps -- which utilize CFC-22 as a refrigerant. ARI actively supported -- and helped make possible -- enactment of this legislation. An integral assumption in the association's strong support was the continued unrestricted use of CFC-22, which, like all the chlorofluorocarbons, is very efficient in heat absorption and transfer. Without this continued use of CFC-22, the air conditioning and refrigeration manufacturers may not be able to reach the energy conservation requirements set by this Congess.

CFC SUBSTITUTES

Our industry would welcome the development of safe, reliable and effective alternative refrigerants for the fully-halogenated CFCs. They would eliminate any concerns about ozone depletion, while at the same time providing a refrigerant whose unrestricted use could be counted on for the long-term. To this end, we have consistently inquired about substitutes and have fully cooperated with the producers of chlorofluorocarbons to perfect substitutes. However, there are limits on what we as CFC users can do until alternatives have been approved for production and made available in quantities adequate for equipment testing.

To date, there are no non-chlorine alternatives available for use as refrigerants in place of either CFC-22 or the fully-halogenated compounds. CFC-123, a chlorofluorocarbon even less ozone depleting than CFC-22, is being investigated for use as a refrigerant in place of CFC-11. Fluorocarbon 134a (or FC-134a) is being looked at as a non-chlorine alternative to CFC-12. It should be noted, however, that these compounds are not intended as drop-in substitutes for existing equipment designs. Instead, if they are used in the future, major costly equipment redesigns will be necessary.

A widely-held perception of late is that FC-134a will ultimately replace CFC-12 as a refrigerant. This perception is dangerously premature, however. Whether FC-134a can be substituted for CFC-12 in central air conditioning and commercial refrigeration systems is presently an open question. Based on our analysis of the literature on FC-134a, we have serious questions about the compound's reliability, safety, performance and chemical/mechanical characteristics, interchangeability potential with existing equipment, as well as the implications for new designs of air conditioning and refrigeration products. We are also concerned that FC-134a might cause electro deposition of copper and copper salts from the motor windings on the internal surfaces of the expansion capillary and on the bearings of the motor and compressor of air conditioners. In addition, we are concerned about FC-134a's reported incompatibility with lubricating oils currently available and used in all kinds of equipment. On top of all of this, it must be recognized that FC-134a has not even passed toxicology tests yet.

As stated above, CFC-123 is being examined as a substitute refrigerant for CFC-11. This alternative chlorofluorocarbon would, if perfected, be significantly less ozone depleting than CFC-11, representing approximately 2% of the ozone depletion potential of -11. Like FC-134a, however, CFC-123 has not passed toxicity tests yet, let alone been made available for testing in air conditioning and refrigeration equipment. Thus, again like FC-134a, it is unclear at this time whether CFC-123 will prove a safe, effective substitute refrigerant for CFC-11.

The situation that ARI finds then with respect to substitutes for the fully-halogenated CFCs is that two substances -- FC-134a and CFC-123 -- are being investigated for use as alternative refrigerants to CFCs 11 and 12 but that far more work is necessary before it can be determined whether they will function safely and effectively in central air conditioning and commercial refrigeration systems. This situation suggests that regulatory approaches, such as those encompassed by S. 570 and S. 571, which essentially phase-out the fully-halogenated CFCs while either phasing out or significantly restricting CFC-22 are on especially precarious footing. They not only phase-out the fully-halogenated compounds, prematurely and incorrectly in ARI's view, they also restrict the use of CFC-22, which could, if necessary, substitute for some uses of CFC-12.

Even if alternatives for the fully-halogenated CFCs are eventually perfected, however, it must be recognized that it will take nine to eleven years from the point where limited amounts of substitutes are made available to manufacturers for initial testing before air conditioning and refrigeration equipment utilizing a substitute refrigerant can be placed on the market. (See chart attached). CFC producers estimate that it will take as long as 5 to 10 years to make CFC alternatives commercially available. This estimate assumes no complications in either the new equipment design or in the safety testing of the substitute refrigerants.

Manufacturers (or users) will need adequate quantities of the substitute refrigerant at some point in the process in order to begin testing the substance in existing designs and to begin developing new designs: The manufacturing process itself takes at least seven years from the product design stage to new product introduction. Moreover, this manufacturing timetable assumes that a newly designed product will not encounter significant operating difficulties after introduction, which would require at least an additional two to three years to overcome. It also assumes that the new equipment will be relatively easy to design and develop, an unknown at this time.

While some of the above steps could be run concurrently in some respects, it should still take up to eleven years, possibly more, to put new air conditioning and refrigeration equipment utilizing a substitute refrigerant on the market. Therefore, any regulatory program regarding chlorofluorocarbons must make allowance for such a time lag. Neither S. 570 nor S. 571 do so, however. S. 571 phases out certain CFCs in less than six years, while S. 570 phases out certain CFCs in less than eight years. Yet, the only substitute refrigerants (other than CFC-22) possibly available in the forseeable future -- FC-134a and CFC-123 -- have not even passed toxicity tests, let alone been made available to the air conditioning and refrigeration manufacturers in testing quantities.

As stated above, it must also be recognized that if the manufacturers of air conditioning and refrigeration systems are required to switch from one refrigerant to another -- whether the conversion is to an existing compound like CFC-22 or a new substance like FC-134a -- instead of simply dropping the new refrigerant into the existing equipment design, they will have to redesign the product. This results from the fact that all refrigerants, whether part of the same chlorofluorocarbon family or not, have their own individual chemical composition and physical properties. For instance, at a given condensing temperature, each refrigerant has its own pressure and at each given evaporator temperature, a different pressure. When it evaporates, each refrigerant absorbs a different quantity of heat for every pound that is circulated in a system. In addition, each refrigerant requires a different amount of space to exist at a given pressure.

The fact that existing air conditioning and refrigeration systems designed to use one refrigerant type cannot merely have a different refrigerant dropped in also means that the large existing stock of equipment in the field must be serviced with the designed-for refrigerant. Therefore, even if we are able to successfully redesign systems using fully-halogenated CFCs to ones using alternative refrigerants, the servicing of existing stock with the old refrigerant must continue if that stock is to remain operative. However, it should be noted that neither S. 570 nor S. 571 address this situation adequately, apparently excluding commercial air conditioners and refrigeration systems from the limited servicing exemption provided for in the bills (as well as by restricting the time-span of the exemption for personal "household consumer goods".)

To serve as an example of the type of servicing necessary today, ARI has made some preliminary estimates concerning the number of large tonnage centrifugal chillers currently in the field. Such chillers, which cool many larger commercial and industrial buildings in the U.S., rely primarily on CFCs 11, 12 and 113 as refrigerants. Based on our calculations, there are currently more than 100,000 large tonnage centrifugal chillers in operation today, providing service to hospitals, large office buildings, hotels, schools, industrial manufacturing establishments, etc. Since these chillers often remain in service for more than thirty years, it can readily be seen that a vast number of systems in use today will have to be serviced with additional replacement refrigerant for years to come. We must also include chillers which will begin operation, whether in new or existing buildings, over the next nine to eleven years. The service requirements of this inventory must be considered.

OTHER CONSIDERATIONS

Conservation Practices

ARI's member companies have become increasingly aware of the need to voluntarily develop and implement conservation practices to reduce emissions of chlorofluorocarbons into the atmosphere and are taking steps to do so. At the manufacture level (where we have actual control of the process), we have taken a number of steps to prevent the escape of refrigerant in our facilities. We have also taken steps to provide guidance in our installation and servicing instruction manuals and equipment literature on good practices in the field, where some central air conditioning and refrigeration systems are occasionally charged or recharged. Manufacturers are also encouraging the recovery, reclaiming and recycling of refrigerants at the field level. It should be noted, however, that the process of reclaiming can be an expensive proposition and also a difficult one because of a lack of reclaiming facilities in many locations. For this reason there are very few commercial reclaiming services in existence. In short, conservation practices offer possibilities in reducing the emissions of chlorofluorocarbons into the atmosphere, and we are committed to pursuing these possibilities to the maximum extent practicable.

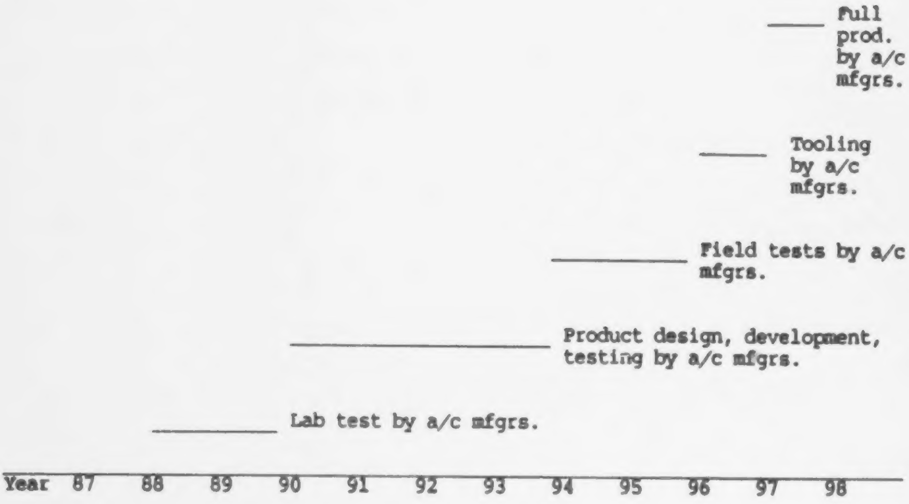
International Trade and Industry Competitiveness

The issues of international trade and industry competitiveness with foreign manufacturers come into play when the matter of unilateral domestic regulation of chlorofluorocarbons is considered. This is because any unilateral U.S. regulations to limit CFC production or use would make it difficult for U.S. air conditioning and refrigeration manufacturers to compete overseas with foreign-made systems not directly subject to the costs of such restrictions. To avoid damage to the industry's export capability, therefore, any U.S. controls on chlorofluorocarbons should be made a coordinated and integral part of a global arrangement supported by the other major industrial nations. Our industry still enjoys a positive export-to-import ratio. We are concerned that this might be risked if restrictions and costs imposed on us are not directly imposed on our foreign competitors also.

CONCLUSION

On behalf of ARI, I wish to thank the subcommittees for holding these hearings in an effort to learn more about CFC alternatives and the impacts future CFC regulations can have. ARI supports responsible measures to address the ozone depletion issue. In late 1986, ARI adopted a policy on CFCs which is attached to this statement outlining such measures. We believe these measures should be agreed to by all the major industrial nations and should focus only on the fully halogenated CFCs --11, 12 and 113, and that CFC-22 be viewed as part of a solution to the issue. Also, it is imperative that before any regulatory approach is agreed to internationally or within the U.S., that the economic impacts are fully understood and that substitutes to CFCs are available. Meanwhile, our industry will continue to seek ways to institute practices to reduce emissions of CFCs into the atmosphere.

ARI
BEST POSSIBLE TIMETABLE FOR A/C MANUFACTURERS TO BEGIN FULL PRODUCTION OF PRODUCTS USING SUBSTITUTE REFRIGERANTS



POLICY OF THE AIR-CONDITIONING AND REFRIGERATION INSTITUTE REGARDING CHLOROFLUOROCARBONS

(As Approved by the ARI
Board of Directors on
November 17, 1986)

The Air-Conditioning and Refrigeration Institute (ARI) has reviewed the questions concerning whether emissions of chlorofluorocarbons (CFCs) into the atmosphere contribute to a reduction in the stratospheric ozone layer and to an increase in the global temperature of the earth ("greenhouse effect"). ARI has taken particular note of the following information:

- CFCs, used among other things as refrigerants in air conditioning and refrigeration systems, are important to the physical and economic well-being of the United States and the global community. For most uses, including that of refrigerants, there are to date no commercially available, acceptable alternatives.
- Certain scientific information suggests that together with other substances CFCs may be contributing in some limited degree to a depletion in the ozone layer and to the greenhouse effect.
- Considerable scientific uncertainty exists, however, regarding the magnitude of any ozone depletion or global warming that may be occuring. In any event, model projections indicate that over the next several decades such effects, if any, will be minimal.
- To the extent that CFCs may contribute to ozone depletion and the greenhouse effect, only the fully halogenated chloroflurocarbons consisting of CFC-11, CFC-12 and CFC-113 would contribute in any significant way to such effects.
- Beyond the current domestic ban on the use of CFCs in nonessential aerosol applications, unilateral regulatory actions undertaken by the United States to control chlorofluorocarbon usage would not lead to significant environmental benefits due both to the global nature of the matters of ozone depletion and the greenhouse effect and to the fact that approximately two-thirds of the world's production of fully halogenated compounds is found outside of the United States.

- Additionally, further unilateral regulation of CFCs by the United States would injure U.S. industry to the benefit of international competition and could undermine efforts to obtain an international resolution concerning CFCs.

Therefore, having considered the above matters, ARI would as a precautionary measure support a global limit on the growth of emissions into the atmosphere of the fully halogenated chlorofluorocarbons consisting of CFC-11, CFC-12 and CFC-113. Any such limit must provide the producers and users of CFCs with adequate advance notice to minimize social and economic disruptions. The following actions should be taken in order to effectuate such a limit:

- The industrialized nations of the world should agree to an equitable basis for limiting the growth of emissions of CFC-11, CFC-12 and CFC-113. Such an agreement would preferably include the less developed nations as well. Because of its characteristics, CFC-22 should be treated by the global community as part of the solution to any problems regarding the greenhouse effect and ozone depletion.
- The United States should refrain from acting unilaterally to further regulate CFCs prior to global agreement. Any further U.S. regulatory actions should be confined to those designed to implement the measures agreed to and adopted internationally.

In an effort to foster precautionary measures to limit the growth of emissions of CFC-11, CFC-12 and CFC-113 on a worldwide basis, ARI would also support the following additional global actions:

- Restrictions on the use of fully halogenated CFCs for nonessential aerosol propellant uses.
- Substitution of feasible alternatives for CFC-11, CFC-12 and CFC-113 where economical and practical.
- Expanded research to find feasible alternative compounds that could substitute for CFC-11, CFC-12 and CFC-113.
- Promotion of voluntary conservation practices to minimize the emissions of CFCs at the manufacture, field installation and service levels.
- Continued scientific research on the environmental impact of CFCs and other trace gases on the stratospheric ozone layer and the global climate.

ARI appreciates its responsibilities to the world community and would as a precautionary measure support any and all of the above described actions. However, such measures must be international, rather than unilateral, in scope and must be limited to the fully halogenated compounds CFC-11, CFC-12 and CFC-113. Actions taken unilaterally or affecting chlorofluorocarbons other than those mentioned would have little, if any, environmental benefit and would harm domestic industry and the American public. Unilateral actions could also undermine international efforts concerning CFCs.

Air Conditioning Contractors of America

Serving the
Independent
Refrigeration,
Heating and
Air Conditioning Contractor

WRITTEN STATEMENT
OF THE
AIR CONDITIONING CONTRACTORS OF AMERICA
TO THE
SUBCOMMITTEE ON HAZARDOUS WASTES AND TOXIC SUBSTANCES
AND THE
SUBCOMMITTEE ON ENVIRONMENTAL PROTECTION
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
UNITED STATES SENATE
MAY 14, 1987

PRESENTED BY
JON PIERCE, PRESIDENT
JON PIERCE INCORPORATED
FT. WORTH, TEXAS

My name is Jon Pierce. I am the President of Jon Pierce Incorporated, an air conditioning contracting company in Ft. Worth, Texas. I am also a Past President of the Air Conditioning Contractors of America, a national trade association which represents approximately 3,000 heating, air conditioning, and refrigeration contractors.

In my testimony this morning, I am representing my own firm -- a small business which specializes in service and replacement work. I am also representing the members of the Air Conditioning Contractors of America. All contractors in the industry are extremely concerned about the ramifications of legislation and regulation which may have a profound impact on our ability to continue employing people and serving the needs of our customers.

INTRODUCTION

Before I present my formal statement this morning, I'd like to relate a story that was told about a County Commissioner who was running for re-election in one of our southern states. The Commissioner was addressing a group of constituents about his position on alcohol. Among those constituents were many prohibitionists as well as a number of voters who operated illegal distilleries out in the hills of the County.

He began his remarks by extolling the many virtues and benefits of alcoholic beverages when taken in moderation: a reduction in tension and stress, the easing of shyness in certain social situations, the benefits of moderate amounts of alcohol in

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**After August 1, 1987, our new address will be
1513 16th Street NW Washington, DC 20036**

courtship and family life, the feeling of general well-being which is gained by the moderate user, and so forth.

On the other hand, the Commissioner noted, there were drastic and unfortunate side-effects of excessive alcohol consumption: automobile accidents, premature deaths, broken and unhappy homes, lost weekends on Skid Row, and so forth.

In conclusion, the Commissioner stated, his clear position on the issue was to approve of the beneficial effects of spirits while standing foursquare against all forms of evil done under the influence of excessive alcohol intake.

If I could paraphrase that Commissioner, I'd state unequivocally that the air conditioning industry is strongly in favor of the benefits which are derived from the use of chlorofluorocarbons: comfort, better health conditions, extended preservation of foods, improved productivity in the workplace, the production of life-enhancing and life-sustaining products, and so forth. At the same time, we are steadfastly opposed to ozone depletion, the greenhouse effect, skin cancer, and premature death.

Of course, the Commissioner's dilemma was to satisfy voters who had different points of view. It had nothing to do with proving the effects of alcohol on users. Those effects were well known.

Our dilemma is to assess the effects of CFCs on our environment and then, if those effects are unwholesome, to decide what to do about these substances. I'd rather we were talking about alcohol or tobacco at these hearings today. The effects of those substances are well known.

Instead, we're discussing a substance which we **think** might have a long-term effect on a stratospheric (ozone) layer which we don't understand at all. Is the hole in the ozone layer over Antarctica the product of chemical action due to CFC emissions or the emission of some other chlorine compound? Or is it the result of a cyclical, dynamic condition which has been recurring periodically throughout the history of our planet?

From what I see and read, nobody really knows the answers to those questions. I certainly don't pretend to know those answers myself. I do know the issue is gray -- not black and white. And under those circumstances, our response ought to tend towards the interim answer rather than a final, possibly tumultuous solution.

Eight or ten years ago, the Federal Government banned cyclamates as artificial sweeteners because they were believed to be cancer causing. New artificial sweetening products were approved as replacements. Ten or so years later, we know that cyclamates are **not** carcinogenic, but the replacement products may be!

In the meantime, a massive dislocation in the soft drink bottling industry occurred -- most small, regional bottlers were forced out of business because they didn't have the resources to react quickly enough to the Federal Government's edict.

Today, the scientific community apologizes for its error regarding cyclamates. That's not much consolation for the small businessman who was driven out of business by that error.

Whatever we do as a government, as an industry, and as a people, we must devise a problem correction system which doesn't arbitrarily chew people up. Whatever we decide to do about CFCs, we must avoid creating a new order which drives people out of business and which throws people out of work.

The most likely scenario which will result from a production limit or ban on CFCs in the air conditioning market will be that the small businessman and the small user -- the little guy -- will lose his business, his job, or his use of air conditioning in his home or office or store. I'm here today to talk for those little guys. They're the ones who have the most to lose.

POSITION OF AIR CONDITIONING CONTRACTORS IN MARKETPLACE

As I stated earlier, I'm an air conditioning contractor from Ft. Worth, Texas. My company services residential, commercial, and industrial air conditioning equipment and systems. We employ seven service mechanics and we do an annual business of about one million dollars.

I'm a little guy, and, according to industry statistics, I am an average air conditioning contractor in terms of my annual business volume and the number of mechanics we employ.

Contractors in our industry employ 455,000 mechanics who are the full-time, principal wage earners in their families. Given the average size of the American family, our industry directly affects 2,000,000 people who depend on us for their wages.

Most homes in America and virtually every business establishment in America depends on a small businessman like me to keep their heating and air conditioning systems operating properly and efficiently. The food processing, storage, and sales industry depends on someone like me to maintain its essential refrigeration systems. The computer industry depends on us to maintain optimum operating temperatures in computer rooms. The list of of people and industries who depend on contractors goes on and on.

Contractors perform a vital service. And, unlike many other industries, our segment of the marketplace is not dominated by giant firms with broad resources. Contractors tend to be small, under-capitalized entrepreneurs who operate on very narrow profit margins.

A miscalculation of two or three percent on job costing will make the difference between a profitable job and a loss. An added expense of only one or two percent can make the difference between winning a job or losing it to a competitor who may not fully understand his total costs.

Being an air conditioning contractor is a difficult and demanding profession. Seemingly small shifts in the economy, seemingly small increases in paperwork burdens, tax and permit fees or regulatory provisions -- any of these factors can have a devastating effect on these small businessmen.

By industry standards, my company uses an amount of refrigerant each year which is typical of most air conditioning contracting firms. During 1986, we used the following amounts:

TYPE OF REFRIGERANT	AMOUNT USED ANNUALLY	APPLICATION
R-22	4,000 pounds	Residential, commercial, industrial, institutional air conditioning
R-502	1,200 pounds	Walk-in freezers
R-113	100 pounds	Environmental chambers
R-12	2,800 pounds	Walk-in coolers, centrifugal compressors
R-11	100 pounds	Centrifugal compressors

Contractors who work exclusively on residential and light commercial systems would use more than 4,000 pounds of R-22; contractors who specialize in large commercial and industrial applications would tend to use more R-11, 12, and 502. Despite those considerations, the usage pattern outlined above for Jon Pierce Incorporated is a useful industry average.

EMISSIONS OF REFRIGERANT IN THE FIELD

Eventually, all of the systems in which this refrigerant is installed will be replaced or suffer severe breakdown. How much of this refrigerant is reclaimed in the field? Virtually none.

When a compressor burns out (after 5-10 years), a new compressor is installed. The refrigerant in a burned out compressor is almost always contaminated with water, oil, and carbon products and is unusable. Standard field procedure is to break the seals and vent the refrigerant to the atmosphere.

In large systems which use 100 pounds of refrigerant or more, some effort may be made during the process of replacing certain controls or components to recapture and reuse the refrigerant (unless the compressor has burned out), but such efforts are relatively rare. It is usually less costly to the consumer if the mechanic simply vents the system, flushes out any lingering refrigerant with nitrogen, installs the new system or components, and recharges with fresh refrigerant.

Is it possible to reclaim the refrigerant from a system which is being serviced or replaced? In some cases, yes. In many cases, it is not possible because the equipment isn't even equipped with the valves and fittings necessary for refrigerant reclamation.

As a practical matter, refrigerant reclaim equipment is limited in its application and is very expensive. In addition, reclaimed refrigerant poses a use and/or disposal problem. Nobody wants to take a chance on installing contaminated refrigerant in a new or repaired system. Contaminated refrigerant will cause damage in the system.

Furthermore, what does the mechanic or contractor do with contaminated and reclaimed refrigerant? There is no "return" system in place, and, if he throws the substance away, it will eventually find its way into the atmosphere anyway.

Current technology favors disposing of unwanted refrigerant in the easiest possible way, venting it to the atmosphere.

In the event that refrigerant became a scarce commodity in the marketplace, new air conditioning systems and equipment would certainly be designed to enable the mechanic to reclaim and reuse a certain amount of the substance. We would be less likely as an industry to casually discard perfectly good and reusable refrigerant. However, the additional time required to recapture refrigerant from a system would impose higher service cost burdens on the consumer.

It is very unlikely that all of the existing air conditioning and refrigeration systems installed in America would be retrofitted with the appropriate valves and fittings which would permit recapture of refrigerant. Such a process would be extremely costly and it is unlikely that the average consumer-user would be willing to pay these costs.

One other principal factor involved in the emission of CFCs into the atmosphere is the existence of small leaks which develop in the fittings and tubing of air conditioning and refrigeration equipment. Such leaks are a common occurrence which the service mechanic attempts to correct while servicing the equipment.

A scarcity of refrigerant would elevate leak detection and repair to a very high priority in the service process. Small leaks which might go undetected and unrepaired today would have to be found and sealed to prevent the escape of a valuable commodity.

The technology to accomplish effective leak detection exists today. Using that technology is a relatively low priority with most service mechanics, however. That's a manageable and correctable problem.

Leak prevention is also a relatively manageable function for the service mechanic. Since many system leaks are caused by vibration of fittings or tubing, rubber bushings and supports can be retrofitted into existing systems to significantly reduce any vibration of these parts.

Some customer-users might balk at paying the higher service costs associated with leak detection and vibration elimination, but a premium price charged for "wasted" refrigerant might overcome these objections in time.

In some cases, refrigerant may be vented through a pressure relief valve because the mechanic inadvertently overcharges the system. Fairly accurate methods of measuring the system charge do exist today. If refrigerant becomes a precious commodity, these superior methods of system charging would enjoy more widespread use.

ELIMINATION OF R-11 AND R-12

One of the solutions proposed for the CFC problem is a severe cutback in production and eventual elimination of R-11 and R-12. Supposedly, systems which use these CFCs would be replaced with R-22 systems or modified so that they could use R-22.

First of all, it is clear that not all R-11 or R-12 systems can be converted to R-22 systems. Those which can be converted will, in most cases, require major and extremely expensive modification to accomodate R-22. It is probable that many R-11 and R-12 users will not be able to afford the costs of conversion.

Secondly, the replacement of R-11 and R-12 systems cannot be accomplished quickly because manufacturers in our industry cannot produce replacement equipment quickly enough to satisfy the needs of the marketplace. Will owners and users of R-11 and R-12 systems be forced to do without air conditioning and refrigeration until manufacturers catch up with demand?

Many commercial office buildings and industrial plants currently have R-11 or R-12 systems in place. During the energy crisis of the last decade, many of those buildings were virtually sealed up to achieve energy conservation. Without air conditioning, a vast number of commercial and industrial structures will be uninhabitable. This is a very serious price to demand on the basis of an unproven theory.

Perhaps we should consider an interim solution similar to that which is being used to phase out leaded gasoline. Allow industry to continue to produce R-11 and R-12 strictly for use in existing, installed air conditioning and refrigeration systems. Phase out or stop the continued manufacture of systems which require these refrigerants.

Natural forces in the marketplace will eventually and steadily eliminate these refrigerants without producing massive dislocation in our economy. If the CFC emission problem is deemed to be too dangerous to allow for such a long term solution, add a final deadline date of January 1, 2000 by which time no further production of R-11 or R-12 will be allowed.

This would offer a time frame during which R-11 and R-12 users could decide when it was economically feasible for them to make the conversion to new systems.

PRODUCTION LIMITS ON REFRIGERANTS

Finally, contractors are extremely concerned about the impact a CFC production limit might have on the marketplace. A production limit might have the effect of encouraging the reclamation of refrigerant, but reclamation is not without problems.

We might see an increase in the recapturing of used refrigerant, but we might also see the introduction of used refrigerant into new systems and newly repaired systems. Some of that reused refrigerant would undoubtedly be contaminated. That could lead to epidemic system breakdowns which would place severe economic burdens on consumers.

A production limitation would also lead to the hoarding of fresh refrigerants by those who had the means to buy them. That would inevitably lead to the dislocation of thousands of contractors (and their employees) who couldn't afford to bid on the available product. It might also lead to forcing economically disadvantaged users to do without air conditioning entirely as the price of this commodity soars in the marketplace.

Finally, we may experience the introduction of refrigerant brokers into the marketplace who would demand excessive prices for this limited product. The end result is all too predictable: insufficiently financed contractors will be forced out of business, and consumers will be forced to pay usurious prices for refrigerant.

Will air conditioning return to its early days when it was a luxury only the rich could afford or when it was a novelty experienced only in the local movie theater? Will we establish a class of "preferred" users who will have relatively easy access to a limited product while other users pay a premium or do without refrigerant?

CONCLUSION

In conclusion, no one in the air conditioning industry wishes to contribute to a breakdown of the ozone layer. While we are not convinced that CFCs are a proven factor in the suspected depletion of the ozone layer, we do not object to a rational and orderly method of reducing CFC emissions.

The Air Conditioning Contractors of America supports the policy regarding chlorofluorocarbons which was adopted by the Airconditioning and Refrigeration Insititute on November 17, 1986. That policy has already been introduced into the record of this hearing by ARI.

We believe that this policy statement offers a reasonable and practical interim solution to the potential problem of CFCs in our atmosphere at this time. We must be careful to protect the jobs and livelihoods of the millions of people who work in our industry or who depend on our industry for a healthy and productive work environment.

We must be careful to choose options and solutions which do not arbitrarily chew people up and force them out of business in the process. In our haste to find a remedy, we may create new horrors which our economy cannot sustain.

MVMA Testimony
before
Senate Committee on Environment
and Public Works' Subcommittee on Hazardous
Wastes and Toxic Substances and Subcommittee
on Environmental Protection

by
Dr. Fred W. Bowditch
Motor Vehicle Manufacturers Association
of the United States, Inc.

Washington, D. C.
May 14, 1987

Mr. Chairman, members of the Subcommittees:

The Motor Vehicle Manufacturers Association of the United States, Inc. (MVMA)* welcomes the opportunity to present its views on the role of chlorofluorocarbons (CFCs) in motor vehicle manufacturing and to outline some steps being taken to address the concerns that have been raised about these highly beneficial chemicals, which are non-toxic, non-flammable, non-corrosive and, outside of their suspected atmospheric effects, environmentally harmless.

The threatened depletion of the earth's stratospheric ozone layer deserves serious attention, Although great uncertainties remain about the exact nature and extent of this threat and its potential impact on human health and the environment, there has been in recent months a growing consensus within the scientific community about the role that certain CFCs can play in ozone depletion and atmospheric warming.

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* MVMA represents U.S. automobile, truck and bus manufacturers producing more than 98 percent of all domestic motor vehicles. MVMA members are: American Motors Corporation; Chrysler Corporation; Ford Motor Company; General Motors Corporation; Honda of America Mfg., Inc.; LTV Missiles and Electronics Group, AM General Division; M.A.N. Truck & Bus Corporation; Navistar International Corporation; Paccar Inc; Volkswagen of America, Inc.; and Volvo North America Corporation.

At the same time, it should also be borne in mind that present scientific evidence does not indicate that current levels of CFC emissions pose an imminent threat to human health or the environment.

Risks from CFC Emissions

CFC emissions reportedly have been linked to stratospheric ozone depletion that would allow an increased flux of UV-B radiation to reach the earth's surface. Increased radiation, as well as other possible climatic effects, have been suggested to constitute potential risks to human health. It must be understood that computer models that have been used to predict ozone depletion contain tremendous uncertainties and are known to be incomplete in their analysis. Depending on future trends for certain atmospheric trace gases included in the computer modeling, ozone could even increase, although such an effect is extremely sensitive to assumed CFC growth rates. Coupled with the fact that the projected medical risks of ozone depletion are uncertain, evidence indicates no imminent threat to human health or the environment from current CFC emission levels. Thus, there is no need for precipitous action; however, it appears prudent to continue investigations to identify alternative refrigerants and then to make some explicit regulatory decisions, once the environmental, engineering and economic concerns are better understood.

Atmospheric Warming

The "greenhouse effect" refers to warming of the earth due to increases in atmospheric levels of certain trace gases, such as carbon dioxide, methane, nitrous oxide, and CFCs. Positive or negative changes in stratospheric ozone caused by chemical effects of these same trace gases will also affect the earth's temperature. Thus, the two problems--i.e., stratospheric ozone depletion and the greenhouse effect--are inextricably related from the perspective of chemical reactions and energy balances in the atmosphere. It should be understood, however, that the greenhouse effect is not a new situation, in the sense that it occurs naturally due to the presence of normal atmospheric constituents such as water vapor, carbon dioxide (CO_2) and clouds. What concerns the scientific community now is deciding to what extent the natural balances in the atmosphere are going to be affected by trace gases of anthropogenic origin. Fortunately, as with the stratospheric ozone layer, there appears to be sufficient time to carefully analyze this situation before making regulatory decisions on the need for control. If we decide to control CO_2 from burning fossil fuels, that would imply drastic global approaches such as massive reforestations of the planet (to absorb CO_2), or increased use of nuclear power, the widespread use of an alternative fuel such as hydrogen, which does not produce CO_2 on combustion. Controls on the other trace gases, which are now estimated to contribute on the order of 30% of the anthropogenic greenhouse effect, would be beneficial in the long term, but are not as likely to have as large an effect as would restoration of the CO_2 balance.

The Need for an International Approach

Before setting priorities for control, much more needs to be known about the worldwide use of CFCs, both present and future. In light of the estimate contained in the December 2, 1986 Wall Street Journal that "an estimated 70% of the world's CFC use occurs outside the U.S.," it appears that even the most stringent unilateral action in the U. S. (i.e., a total ban of CFC production and use) would have only a temporary impact on current global emissions. In the long term, this impact would become insignificant, as an increase in demand for CFCs by developing nations and the rest of the industrialized world surpasses the finite U.S. reduction. Such a scenario was observed as a result of the U.S. ban of CFCs used as aerosol propellants in the late 1970's; that reduction has now been negated by increases in CFC usage outside the U. S., and total emissions are as high as they have ever been.

U.S. user industries competing with those of nations with no corresponding regulations will be adversely impacted because they will be economically penalized by having to incur higher costs to manufacture and market competing products. These include new and/or higher costs associated with: additional research and development, redesign and retooling of existing manufacturing processes, purchase of CFC substitutes, or added expenses related to taxation/fees of current CFC supplies, etc. In turn, this will reduce the overall competitiveness of those U.S. industries. Also, should CFC regulation, such as a CFC production cap, limit the availability of CFCs, CFC producers could be afforded an artificial profit opportunity.

We are concerned with the present UNEP negotiations which are proposing a possible 20% reduction by 1992, because the U.S. already has taken a major step toward reducing CFC emissions by banning their use in aerosol products. Any international agreement should recognize this fact and credit the U.S. with the reductions achieved to date. Lack of such recognition will put present U.S. industries at a trade disadvantage.

Motor Vehicle Usage

Three suspected ozone depleting CFC compounds are presently used in the motor vehicle manufacturing process. They are CFC-11, CFC-12, and CFC-113:

> CFC-11 is used in the flexible foam blowing process to produce seat cushions and padding to improve occupant crash protection.
>
> CFC-12 is used as a refrigerant in mobile air conditioning.
>
> CFC-113 is used as a cleaning solvent in degreasing parts and in the manufacture of electronic components which play an important role in fuel economy and exhaust emissions control.

In terms of usage, CFC-12 is the most important. A recent Rand study (1) has estimated that 37% of the CFC-12 produced in the U.S. goes for charging and servicing mobile air conditioning. Of that amount, new vehicles account for only 20-25% of the CFC-12 used each year. The rest, 75-80%, is used to service existing vehicles - and there are an estimated 90 million cars and trucks on the road today with factory installed air conditioning, not to mention the millions of A/C units provided by aftermarket manufacturers over the years.

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(1) James K. Hammitt, et al, Product Uses and Market Trends for Potential Ozone-Depleting Substances, 1985-2000, May 1986. p.6.

Substitutes

With respect to certain foam blowing applications, one possible alternative for CFC-11 is a water-blown process, which would require an estimated 2-3 years to accomplish. The main question that needs to be answered is whether the current softer densities can be consistently produced. For other applications, substitutes may require up to 5 years.

As for solvents, there are no substitutes with all the desirable properties of CFC-113. While some substitutes might be used in the manufacture of electronic parts, reliability would be reduced. However, with CFC-113, it may be possible to adopt industry-wide facilities which permit nearly 100% recapture and recycling of the solvent, and thereby virtually eliminate emissions to the atmosphere.

There is no readily available alternative refrigerant to CFC-12 that can be used in today's existing automotive A/C systems.

One potential alternative, CFC-22, would require a complete redesign of the A/C system, new hose material and a new lubricant. A recent (draft) report by the Radian Corporation (2) states that CFC-22 has one fourth the ozone depleting potential of

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(2) "Chlorofluorocarbon Chemical Substitutes"; December 4, 1986; EPA Contract No. 68-02-3994; Draft Report. (Final Report scheduled in June '87 - the above data is not expected to change.)

CFC-12. Physical properties of CFC-22 require a higher system operating pressure which would lead to greater permeation losses and resulting higher recharging frequency. According to one manufacturer, a minimum of 7-8 years would be required to develop such a system for production. A major drawback is that, even if the industry were to convert to CFC-22, and this refrigerant were released to the atmosphere in quantities of the same or greater magnitude that EPA projects for CFC-12, the industry could once again be forced to seek another alternative because of the residual ozone-depletion effect of CFC-22. Cost estimates, developed in 1980 by the domestic industry indicated that such a massive system conversion cost would approach $650 million. Capital expenditures of that magnitude are not justified for what may be a short-lived interim measure. The fact that both Senate Bills, S.570 and S.571, introduced in February 1987 identify CFC-22 as a substance of concern does not give our industry much confidence in considering this substitute.

Another alternative that has been suggested is the mixture CFC-142b/22. While use of this refrigerant may be technically feasible in existing compressors, service problems remain. Development of new hose material and a new lubricant would be needed. Known hose materials allow the escape of some of the CFC-22, leaving a highly flammable mixture, which makes this choice unacceptable as an alternative.

A promising alternative that is receiving much attention from both producers and users is the fluorocarbon FC-134a. This refrigerant has performance characteristics similar to CFC-12, but is not considered to deplete the ozone, because it contains no chlorine. However, there are many unanswered questions concerning the engineering performance, safety, toxicity, and manufacture of FC-134a that need to be resolved. The steps that must be taken to answer these questions for any new alternative refrigerant are shown in Figure 1 and discussed briefly below.

Leadtime

Any new refrigerant requires careful assessment of environmental impact and engineering requirements relative to both its manufacture and application. Thus, some appreciable quantity of the new refrigerant must be available to both the refrigerant and vehicle producers, so that preliminary assessments may be made simultaneously and early during the program, to determine if the candidate compound is suitable. Further, before any assessments begin, the refrigerant, which may be purchased from different suppliers, needs to be screened to make sure it is in fact of suitable and representative purity. So far as MVMA is aware, no commercially viable manufacturing process for FC-134a has yet been developed.

Once the preliminary assessments have been successfully completed, long term toxicity tests and in-use field tests may be conducted simultaneously to minimize lead-time, although such an approach is not without risks. For instance, one known technical problem with FC-134a, that has been of concern to both the automobile industry and the home appliance industry, is the identification of a compatible lubricant and the prevention of electrodeposition of copper in mobile A/C systems when using this refrigerant.

Actual ordering of the necessary equipment and the facilities required for volume production of either the refrigerant or the mobile A/C system must await the final results of long-term toxicity tests and actual in-use field tests. At some point before the end of these long-term tests, tentative results may look sufficiently promising that the risk of placing equipment orders might be acceptable.

This process is estimated to require 7-8 years to complete, as shown in Figure 1. Some manufacturers believe another 2 years may be required to incorporate the new system into all assembly plant production lines across the U.S.

Consequently, the kind of phased-in CFC reduction schedules proposed in S.570 and S.571 that would begin in 1989 are unrealistic. For example, a substitute for CFC-12 in mobile air conditioning cannot be phased into use until it is tested, available and in production.

The overall task before us, therefore, is indeed a long and complex one; however, some steps have already been taken.

Discussions are underway with EPA for joint government and industry research programs. Such research could help eliminate duplicative, costly research efforts, and provide assurance that the results would be credible and available to others.

Conservation and Recycling

Over the last ten years, motor vehicle manufacturers have taken a number of steps to reduce the weight and improve the efficiency and performance of A/C systems. For example, the initial mobile A/C unit factory charge has been reduced from an average of nearly 4 lbs. of CFC-12 in the '70s, to about 2 1/2 lbs. today. As a result, the 9.9 million A/C equipped vehicles produced in the U.S. in 1986 on average required about 35% less CFC-12 than before (3). Improvements have also been made in containment, with new hose material reducing leakage rates by some 75% (to an average of about 0.25 lbs. per year) compared to ten years ago.

Vehicle manufacturers are investigating methods to minimize the release of CFC-12 through the use of improved elastomeric hose material, improved couplings, and methods to recycle the CFC-12 removed during the service process. While improvements have been made in the materials and attachments, more significant reduction in the release of CFC-12 to the atmosphere in the near term would be made if the refrigerant could be recycled during servicing of the A/C system. This would require every auto dealership and A/C service facility to have a small unit capable of recycling and cleaning up the refrigerant to some predetermined specification. At this time, it is not even known how pure the recycled refrigerant must be in order to work in present air conditioning systems. Development of a specification for recycled refrigerant and a portable unit to do the recycling is possible and might contribute to reduction of CFC-12 releases.

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(3) A one year comparative saving of 13.9 million lbs. (9.9 million cars and trucks x 1.4 lbs of CFC-12).

Nevertheless, two regulatory problems would have to be addressed: 1) enforcing the requirement to recycle the refrigerant, rather than vent it to the atmosphere, may be very difficult without some economic incentive; and 2) with present servicing procedures, release of CFC-12 to the atmosphere is almost inevitable when a customer takes a non-working A/C system into the repair shop. The first thing that is done is to charge the system, either to identify a leak or to check out the overall system performance. If there is a leak, this charge is lost to the atmosphere. It would, therefore, appear useful to look into the development of an economical alternative method to check for leaks in A/C systems. Several such alternatives are being investigated.

Summary

In summary, let me underscore the following points:

o Stratospheric ozone depletion, if significant, is a global problem requiring an international response. Therefore, MVMA discourages unilateral U.S. action which would have only a temporary impact on current global CFC emissions, and expose U.S. industry to a competitive trade disadvantage. MVMA urges the adoption of an effective international accord for cooperative action.

o There is no need for precipitous action; however prudent steps to identify and resolve the questions regarding suitable alternatives to ozone depleting chemicals should proceed.

- Motor vehicle manufacturers are actively pursuing such investigations.

- With respect to foam blowing, one possible alternative for CFC-11, is a water blown process which would require an estimated 2-3 years to accomplish.

- With respect to solvents, there are no substitutes equal to CFC-113. However, with CFC-113 it may be possible to adopt industry-wide facilities which permit a nearly 100% recapture and recycling of the solvent.

- A substitute for CFC-12 in mobile air conditioners requires thorough testing to ensure it is technically sound, environmentally safe and economically feasible. This process is estimated to require seven to eight years to complete. Some manufacturers believe another two years may be required to incorporate the new system into all assembly plant production lines across the U.S.

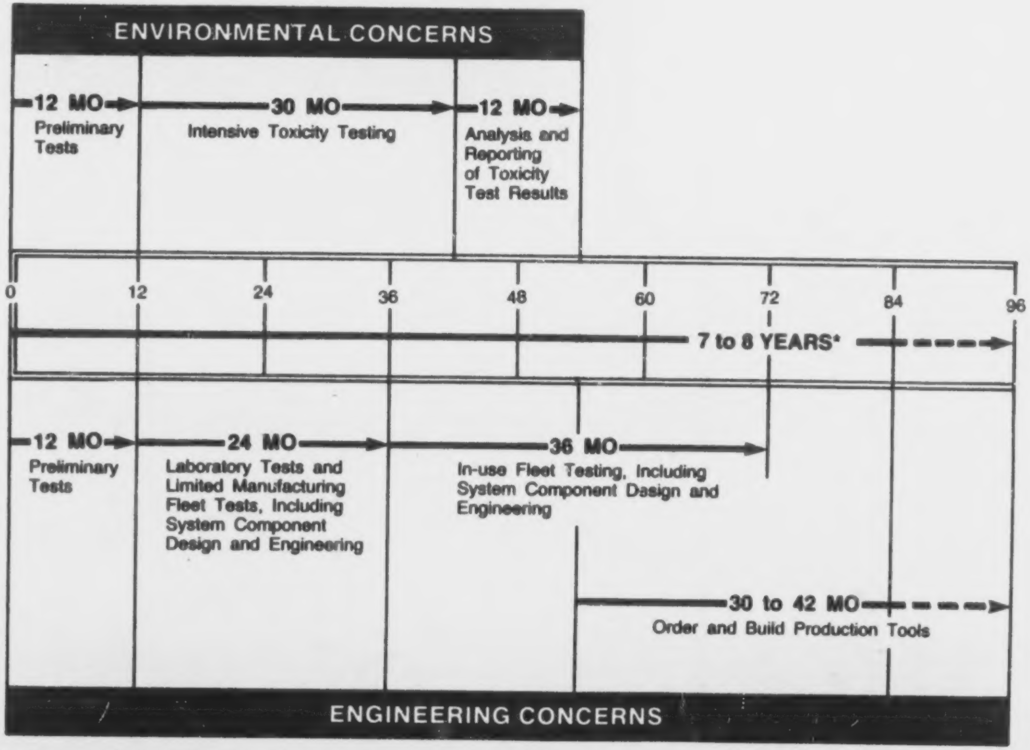
- The kind of step-down reduction schedules proposed in S. 570 and S. 571 are unrealistic. For example, a substitute for CFC-12 in mobile air conditioning cannot be phased into use until it is tested, available and in production.

- For mobile air conditioning, CFC-12 will still need to be produced for 10 to 15 years after the introduction of a substitute in order to service the approximately 100 million car and trucks with A/C units already in use.

MVMA appreciates the opportunity to testify.

FIGURE 1

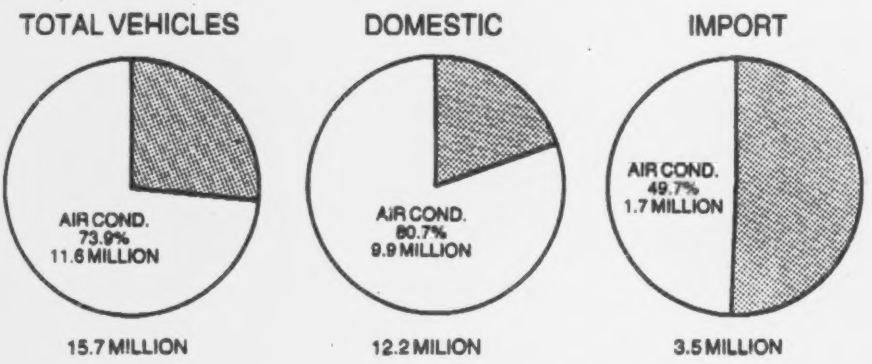
Estimated lead-times before vehicle production can take place, after start of toxicity and engineering tests for new refrigerant, assuming no setbacks are encountered during testing.


ENVIRONMENTAL CONCERNS
12 MO
Preliminary Tests
30 MO
Intensive Toxicity Testing
12 MO
Analysis and Reporting of Toxicity Test Results
0
12
24
36
48
60
72
84
96
7 to 8 YEARS*
12 MO
Preliminary Tests
24 MO
Laboratory Tests and Limited Manufacturing Fleet Tests, Including System Component Design and Engineering
36 MO
In-use Fleet Testing, Including System Component Design and Engineering
30 to 42 MO
Order and Build Production Tools
ENGINEERING CONCERNS

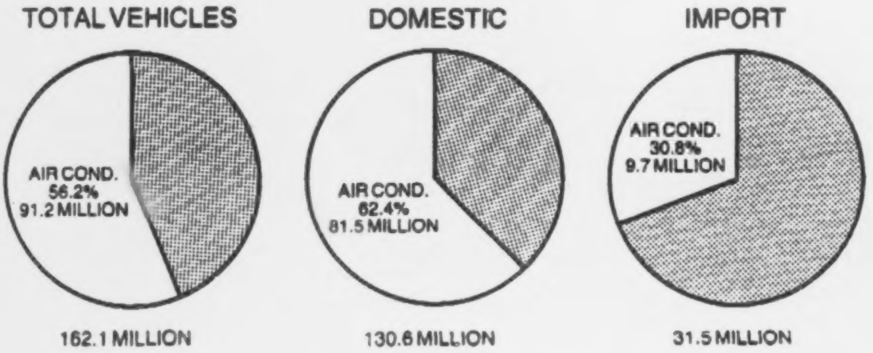
* Some manufacturers believe another two years may be needed to incorporate the new system into all production lines across the U.S.

FACTORY INSTALLED AIR CONDITIONING

NEW VEHICLES – 1986 MODEL YEAR
CARS AND LIGHT TRUCKS



VEHICLES IN-USE AS OF JULY 1, 1986
CARS AND LIGHT TRUCKS



Factory Installed Air Conditioning - 1986 Model Year

Automobiles

	Domestic	Import	Total
Sales	8,543,732	2,619,425	11,163,157
Factory Air	7,562,508	1,570,962	9,133,470
Percent	88.5%	60.0%	81.8%

Light Trucks/Vans

Sales	3,696,865	885,651	4,582,516
Factory Air	2,324,643	171,877	2,496,520
Percent	62.9%	19.4%	54.5%

Cars & Light Trucks

Sales	12,240,597	3,505,076	15,745,673
Factory Air	9,887,151	1,742,839	11,629,990
Percent	80.7%	49.7%	73.9%

Source: Ward's Automotive Reports

Vehicles in Use With Factory Installed Air Conditioners
(Units in Thousands, as of July 1, 1986)

Model Year	Vehicles in Use				% With Factory Installed A/C				** Vehicles in Use With A/C
	Dom. Cars	Imp. Cars	Dom. Trucks	Imp. Trucks	Dom. Cars	Imp. Cars	Dom. Trucks	Imp. Trucks	
1986	4936	2136	2295	768	88.5%	60.0%	62.9%	19.4%	7243
1985	7710	2822	3542	676	87.2%	53.7%	61.3%	18.2%	10533
1984	7803	2495	3060	736	84.0%	48.2%	58.7%	10.4%	9630
1983	5434	2150	2091	380	83.5%	47.6%	54.8%	9.7%	6744
1982	5088	2126	1770	373	80.7%	42.3%	52.6%	7.9%	5966
1881	5692	2190	1704	324	76.4%	36.3%	47.0%	7.7%	5969
1980	5897	2311	1715	312	73.0%	31.3%	40.6%	15.3%	5772
1979	7420	1863	3308	272	79.8%	26.8%	39.7%	14.3%	7773
1978	7360	1680	2985	306	80.8%	30.7%	41.2%	12.5%	7731
1977	6968	1157	2658	244	81.7%	27.1%	38.2%	10.5%	7047
1976	5425	988	2060	198	74.0%	21.3%	33.3%	2.1%	4915
1975	3562	574	1464	113	72.6%	19.3%	30.6%	N.A.	3145
1974	3429	829	1725	150	67.9%	N.A.	N.A.	N.A.	2328
1973	3327	603	1592	182	72.6%	N.A.	N.A.	N.A.	2415
1972	2474	518	1317	142	67.5%	N.A.	N.A.	N.A.	1670
1971	1580	450	890	106	63.4%	N.A.	N.A.	N.A.	1002
<'71*	7156	1107	5179	198	17.8%	N.A.	N.A.	N.A.	1275
N.A.	8	2	9	1	N.A	N.A.	N.A.	N.A.	N.A.
								Total	91157

Notes: * The installation rate for years prior to 1970 (17.8%) is the calculated average for model years 1955-1970.

** The figures in this column are the sum of the products of the multiplication of vehicles in use by a/c installation rate for each of the four types of vehicles.

Caveats: The truck "Vehicles in Use" figures include all types of trucks (light, medium, and heavy) while the a/c installation rates are for light-duty trucks only. No medium- or heavy-duty a/c installation rates are available. It should also be stressed that the installation rates given for all types of vehicles are for factory installations only. In the case of imported vehicles, in particular, the omission of aftermarket a/c installations may significantly understate the actual number of air conditioned vehicles in use. No aftermarket installation data are included.

Sources: "Vehicles in Use" data are from R.L. Polk & Co. "% With Factory Installed A/C" data are from Ward's Communications, Inc.

N.A. = Not Available

DKW 4/13/87

**The Society of the
Plastics Industry, Inc.**

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Statement

of

Mr. Neil Ganser

Ganser, Inc., Bozeman, Montana

for

The Society of the Plastics Industry, Inc.

before

The Subcommittee on Hazardous Waste and Toxic Substances

and

The Subcommittee on Environmental Protection

of the

Committee on Environment and Public Works

United States Senate

May 14, 1987

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PAST PERFORMANCE—FUTURE PROGRESS

Mr. Chairman, Committee members, I am Neil Ganser, President of Ganser, Inc. Thank you, Senators, for inviting me to testify. I am from Bozeman, Montana. I am a contractor/producer of spray-in-place polyurethane foam insulation products. Mine is one of several segments of the plastics foam industry totally dependent upon chlorofluorocarbon chemicals (CFCs). I appreciate this opportunity to present the views of The Society of the Plastics Industry, Inc. (SPI).

SPI is a trade association. It is composed of approximately 1,900 member companies and individuals who supply raw materials; process or manufacture plastics of plastics products; engineer or construct molds or similar accessory equipment for the plastics industry; and engage in the manufacture of machinery used to make plastics products and materials of all types.

SPI member companies with a specific interest in the subject of this hearing include the manufacturers of raw materials used in making rigid foam plastic insulation, flexible polyurethane foam, fluoropolymers and polyurethane insulating spray foam contractors. Our industry uses approximately 30% of the CFCs produced in the United States. It is very significant to note that 20%-30% of the cost of our products is attributable to CFCs. For example, one of our member companies analyzed the impact of tripling the cost of the CFC blowing agent. The study concluded that 50% of the existing rigid polyurethane market for roofing and siding would be lost. Further, the study concluded that substitutes would in general be more flammable and poor insulators. Therefore, any Congressional actions related to CFCs would have a major impact on our industry.

I will describe the several CFC-using segments of the plastics industry and then tell you a little more about my business.

Foam plastic insulation products -- including spray-applied and rigid board stock polyurethane or polyisocyanurate foams, phenolic foams, and extruded polystyrene foams -- are used in building construction, both residential and commercial, in home and commercial refrigeration insulation, in refrigerated truck and rail cars, and for tank and pipe insulation. These plastic foam insulation products offer highly desirable properties, including high insulation value and strength, to meet the variety of needs of American consumers.

CFCs are used to make flexible polyurethane foam as well as rigid polyurethane insulation. Flexible polyurethane foam is used as the principal cushioning material in furniture and automobiles, bedding, carpet cushioning, textile laminates and for packaging.

In 1985, the most recent figures available for polyurethane foam alone, this represents the manufacture of 2.13 billion pounds of polyurethane, 65% for flexible foam, and 35% for rigid foam. Twenty percent of the rigid foam was used for spray-in-place applications like those my company performs.

Extruded polystyrene sheet made with CFCs is used for coating glass soft drink bottles, making certain foam cups and dishes, and fast food packaging and meat trays found in the local supermarket. Polyolefin foam, which is used for packaging sensitive electronics and military equipment, is also made using CFCs. Finally, in the plastics industry, CFCs are used to make fluoropolymers which are used in the electrical and electronics industry, and in chemical processing equipment and for non-stick coating.

CFCs are used to make plastic foam insulation because they provide the highest levels of insulation efficiency per unit thickness for energy conservation. While CFC-11, and to a lesser extent CFC-12, acts as an expansion agent during foam formation, its primary function is to remain in the foam as an insulating gas. CFCs have a very low thermal conductivity which results in excellent resistance to heat transfer. CFCs have a number of other characteristics which make them highly desirable to use: they are relatively safe in the workplace as they are non-flammable and have very low toxicity characteristics. They are chemically inert and have excellent compatibility with other materials. Any proposed substitute must meet all of these characteristics.

The plastic products made with CFCs make substantial contributions to energy conservation efforts, to our lifestyles, and to the national economy. The technical qualities of the finished products made with CFCs are largely dependent upon CFC use.

Before I proceed, I want to discuss the ozone depletion issue briefly. I am not a scientist, but I understand that there are many theories about the extent and causes of ozone depletion. The theory most people have concentrated on is the theory that a chemical reaction occurs in the stratosphere in which ultraviolet radiation destroys CFCs. The chlorine released from CFCs then reacts with the ozone. Others believe that ozone depletion may be due to natural phenomena like volcanic eruptions and the winds. The ozone "hole" observed in the Antarctic is thought by some to be attributable in large part to the geographic and weather conditions peculiar to the region: the long periods of darkness and extremely cold temperatures. It is my understanding, however, that the scientists participating in the recent expedition in Antarctica to study ozone depletion performed numerous experiments but failed to prove or disprove that any single theory or mechanism is responsible for ozone depletion. Additionally, there appears to be no imminent threat to human health or the environment from the current levels of CFC emissions.

So long as current scientific understanding of the ozone depletion theory remains uncertain and assumptions about emissions of ozone-depleting substances are not proven, proposals to phase out over a 6 to 8 year period virtually all production of the CFCs we rely on in our businesses are extreme. Given the concerns about ozone depletion, however, SPI agrees that some responsible international action is warranted which will address environmental concerns while limiting the disastrous economic consequences we will face if extreme measures like those being proposed here are adopted. SPI, as a member of The Alliance for Responsible CFC Policy, generally supports the policy of The Alliance, including (1) the negotiation of an international agreement under the auspices of the United Nations Environment Program to achieve a global production capacity cap for the fully-halogenated CFCs; (2) the development of voluntary CFC conservation programs by user industries; (3) the continued development of scientific understanding of the ozone depletion theory; and (4) research into and development of alternative CFC products and processes to reduce reliance upon the fully-halogenated substances.

We think it is critical that any control initiatives be global in scale. We feel strongly that given the universal nature of the suspected ozone depletion problem, the U.S. response to the concerns should not be unilateral. Unilateral action will not achieve environmental goals; however, it will punish American industry and cost American jobs. The rest of the world must share the responsibility for protecting our environment. It is the responsibility, SPI believes, of the United States government to make this a high level priority and direct its energies to put pressure on other countries, as necessary, to join in an ozone protection agreement. We are encouraged by reports that significant progress on this score has been made in the recent meetings held in Geneva under the auspices of the United Nations Environment Programs (UNEP) and believe that an international agreement on the issue can be reached this year.

The United States government must refrain from precipit_ action to regulate or restrict CFCs. Such action would jeopardize the U.S. negotiating posture in UNEP by eliminating the incentive for CFC producers in other countries to develop alternative materials and for users to adapt their processes and equipment for their use. We would urge Congress to support, not undermine, the international negotiations.

Senators, I'd like to tell you more about my business. I first became interested in spray-in-place polyurethane foam insulation products in the mid-1960's as a high school student. Having grown up around construction, it was easy to see that this product had unique and special construction capabilities. Spray foam insulation has a high degree of thermal resistance, largely due to the use of CFCs. It is an important factor in helping the U.S. meet energy conservation goals. Aside from residential and commercial construction, spray foam insulation is used to insulate facilities built to store bulk food products like potatoes, onions, and apples, and in livestock confinement buildings like turkey sheds. It is even used in space on the shuttles. The spray-in-place feature allows us to insulate structures of unusual design. In addition to insulating, spray foam products can add tremendous strength to a building, particularly valuable in earthquake zones, such as southwest Montana. Also, spray foam is increasingly being used to prevent infiltration of radon gas into homes.

Spray-in-place foam insulation is so versatile that a crew may go from spraying a house cavity wall, to a spray roofing job on a factory, to a walk-in freezer, to pouring taxidermy forms, to forms for iron foundry casting, to undercoating a semi-tractor trailer for the Alaskan highway truckers, to filling buoys for marking river channels and foaming flotation insulation on civilian and military water craft, to an underground mine to stabilize rocks for mine personnel safety. My crew can go from insulating an outdoor hot tub, to a mobile television control center for the Olympic Games, to the Pioneers Museum, to digestor lids on waste water treatment plants, to a flower delivery truck, to a drinking water storage tank in Yellowstone Park, to seedling enclosures for the U.S. Forest Service. Members of the crew carry their lunch daily in a small cooler insulated with polyurethane pour foam, as is their family picnic cooler and the energy efficient hot water heater, refrigerator and freezer in each of their homes.

Spray-in-place polyurethane foam sounds like a product worth getting interested in, doesn't it? I got excited about this product's capabilities in construction and started selling and installing it in 1978. I have been in business for 12 years. In 1981 we began wholesaling the raw materials over a 2 state area and in 1983 began a research and development program to develop our own name brand system. This new system took 3 1/2 years to perfect and is now trademarked the CORBOND ® Performance Insulation System. This is a system especially designed for the modular and mobile home markets. Ours is an excellent product which at last makes super energy efficient housing available to the less than affluent home buyer. My employees and I make our livings selling this product to people who will appreciate its qualities for years to come and therefore appreciate the people who provide it to them.

We have been successful in these endeavors because we have an excellent product. We have attracted good people who are ambitious and independent. We have borrowed money and paid it back. We have never asked for anything from the government and never used an SBA, FHA, or VA loan, but did it on our own and paid the price at market rates. Today, my business and several hundred thousand dollars worth of equipment is totally paid for.

If Senator Baucus' or Senator Chafee's legislation is enacted, I will be hurt severely, as will the rest of the plastics foam industry. The years of work of myself, my employees and thousands of others will be worthless. These bills call for extreme action without paying heed to economic costs for small businesses.

As I have stated, I am not in a position to judge the theories relating CFCs to ozone depletion. I also am not eager to have the world's climate changed unnaturally for I, too, am an environmentalist. I have always felt that my company contributed to a better environment, and I get very frustrated when I see the environmental benefits of our insulation products being ignored. The high insulation value of CFC-blown foam plastic insulation results in the dramatic conservation of energy. The use of these products reduces the need for combustion of fossil fuels like high sulfur coal to provide energy, and thus helps limit the environmental damage from such things as acid rain. Energy conservation has been one of our national goals for over a decade. Enactment of the two CFC bills I've referred to would reverse the direction. For your information, in response to this national goal, several years ago Congress created the Northwest Power Planning Committee to plan for energy use in the Northwest. This Committee is presently promulgating building energy codes that can be met most efficiently with CFC-blown plastic foam insulation products.

The proposals pending before this Committee call for a freeze of production of CFCs at 1986 levels by next January and a 25% reduction by January 1, 1989. There is no doubt that upon imposition of a freeze the price for CFCs will go up. This alone will price some applications out of the marketplace. A 25% reduction in CFCs 18 months later obviously will result in prices being driven much higher, resulting in economic disaster for those of us for whom CFCs represent a very significant part of the product cost in our materials-intensive industry.

It has taken 25 years for the spray-in-place polyurethane insulation industry to mature. These proposals could effectively demolish my industry in 18 months, eliminating jobs and impairing national goals of energy efficiency in products and houses. I urge you to avoid taking unwarranted precipitous action.

I would like now to attempt to answer some of the questions posed by the subcommittees.

(1) Which CFCs do we use, and what are the rates of CFC emissions?

In the plastics foam industry, the principal CFCs used are 11 and 12. CFC-11 is used for rigid polyurethane foam insulation and for flexible polyurethane foam. CFC-12 is used to make extruded polystyrene insulation and extruded polystyrene sheet.

Information on CFC emissions rates is imprecise. For insulation, it is generally estimated that 85% - 95% of the CFC is encapsulated within the closed cells at the time of manufacture. About 5%-15% of the CFCs used in manufacturing insulation is therefore emitted into the air at the time of manufacture, depending upon the process.

It is difficult to quantify the CFC emissions from insulation over the life of the product, but ultimately the CFCs will very slowly be emitted over a very long period of time. I am aware of a recent study on polyurethane foam that estimates a half life in excess of a hundred to perhaps three hundred years. For extruded polystyrene foam, the half life is reported to exceed 50 years.

CFC emissions from flexible foams are prompt since their cells are open to the atmosphere. The blowing agent escapes from the foam relatively quickly. During foam curing and storage, 35 to 45 percent of the CFCs is emitted. Another 15 to 20 percent is emitted during cutting and similar operations. For flexible polyurethane, then, virtually 100% of the CFCs used are emitted within a short time of actual manufacture.

(2) Is recycling possible?

In my industry, that of spray-in-place polyurethane foam, recycling is not possible because of its on site application character. For polyurethane manufacturing plants, some have proposed using carbon adsorption beds to control CFC-11 emissions. These carbon beds will also adsorb the principal chemical elements of the foam. Because of the massive air flow volumes required for the foaming process (30,000 ft^3/min) and the low levels of CFCs to be captured (200 ppm or less) enormous adsorption beds would be required. The cost of such a system would be prohibitive --approximately 1 and 1/2 times the cost of the rest of the production operation.

(3) What chemical substitutes are commercially available?

For the plastics foam insulation industry, using primarily CFC-11 and CFC-12, there are no commercially available substitutes. Polyethylene foam is made with CFC-114, for which there is likewise no substitute. For non-insulating CFC-made plastic foam products, some substitutes do exist; however, their use involves tradeoffs and costs.

Extruded polystyrene sheet, currently made with CFC-12, can be made with pentane. This substitute is more flammable than CFCs. Its use would result in increased workplace safety and health concerns. Insurance requirements may also change as a result, with increased cost to the manufacturer.

Substitutes also exist to a certain degree for flexible polyurethane foam. Currently, approximately half of the flexible polyurethane manufacturers use methylene chloride in lieu of CFCs; however, certain super-soft grades which are highly desirable by consumers cannot be made with methylene chloride. There are concerns about a complete switch to methylene chloride because of the current debate about its health effects, including potential carcinogenicity (although tests on this point have been inconclusive). CFCs provide a means of producing both low density foams for use in furniture backs and the like, and also of producing softer and more comfortable high-density foams for use in deep cushioning. CFCs also may perform an important technical function in the manufacture of flexible polyurethane foam. They exert a cooling effect on the exothermic reaction which occurs in foam manufacture and reduce the risk of overheating and fire.

Use of substitutes like pentane also create environmental concerns as they result in volatile organic compound (VOC) emissions to the ambient air. VOCs are known to contribute to ground level ozone formation. As you know, Congress is already being asked to help EPA deal with the non-attainment of the ozone standard in many parts of the country. As a result, extruded polystyrene sheet operations in non-attainment areas probably would not be able to convert because they could not get the necessary environmental permits to use materials which create VOCs.

CFC producers indicate that a possible substitute for CFC-12 used in extruded polystyrene foam, CFC-22, currently is available. CFC-22 is widely used in air conditioning and refrigeration. Converting to CFC-22 for foam blowing would require extensive equipment redesign, however, Further, CFC-22 may not be a practical substitute as some indicate it diffuses out of the foam in less than 6 months, thereby making the foam lose most of its insulating value.

(4) What substitutes may become commercially available in the future?

In evaluating a substitute for the currently used CFCs in foam insulation products, the following factors must be considered: thermal conductivity value, vapor pressure, flammability, toxicity, and solubility. Without good thermal conductivity characteristics, similar to those of CFCs 11 and 12, foam will be less desirable as insulation. If the chemical is soluble, it could more quickly diffuse from the foam, leading to loss of insulating value. Without adequate strength properties, the foam will collapse.

CFC producers have identified some potential substitutes for CFCs 11 and 12. CFC-123 and CFC-141B have been identified by CFC producers as possible substitutes for CFC-11. I understand some in industry who have been looking more closely at CFC 123 believe that it may not be a viable substitute because the insulating ability of the gas is 20 - 30% less than CFC-11. Problems in foam flowability may also exist. CFC-134A has been identified as a potential substitute for CFC-12, but whether it would work in our applications is still unknown, and preliminary toxicology studies are incomplete. Another alternative, CFC-133A, is an embryotoxin, so is generally considered disqualified. CFC-142b has also been identified as a possible substitute for CFC-12. CFC-142b is flammable however. This may create workplace hazards.

All of these alternatives will require a great deal more study to assess their toxicological, physical and chemical properties before more in-depth product development work begins. Currently, only very small quantities of these substitutes are available for analysis, in the 1 to 5 gallon range. This limited quantity will permit limited laboratory analysis of solubility, toxicity and flammability. It is unclear whether actual processing can be done in the near future, even with the more promising substitutes. It is estimated, for example, that a single trial full-scale processing run will require a minimum of one 55 gallon drum of the alternative CFC for either rigid or flexible polyurethane foams. Clearly, if problems in flowability are encountered, experiments with different amounts of the alternative or different additives will be necessary before an insulation product can be commercially made.

Even ignoring what will certainly be dramatically higher prices for substitutes, with insulating values estimated to be 20 percent or more lower than those associated with CFCs 11 and 12, many applications of plastics foam insulation will lose their ability to compete in the marketplace.

To the extent that alternatives to CFCs provide less effective energy efficiency than currently used CFCs, increased thicknesses of products will be necessary to maintain insulating ability. This could lead, for example, to a reduction in the interior capacity of home refrigerators, refrigerated trucks and refrigerated railcars to accomodate new requirements in insulation thickness while maintaining the same overall appliance size or meeting specifications limiting overall truck and railcar sizes. This would also lead to increased energy use requirements. The problem would be magnified in building construction applications. For example, wall assemblies would be more expensive because they would require more materials to accomodate thicker insulation.

(5) How long will it take to incorporate chemical substances into your system?

As users, we are totally dependent upon the CFC producers to develop and produce substitute chemicals. CFC producers are estimating that full scale commercial availability of CFC alternatives is about 5 years away. Basically, we estimate that a minimum of 7-10 years will be required before substitutes can be used in our processes.

Producers of CFC alternatives must first identify the best processes for the commercial manufacture of alternatives, develop pilot plants to provide sufficient quantities of the products and begin long term toxicity and applications testing. Work on this score is ongoing. If the initial toxicity and application results are promising and pilot plant evaluations are favorable, design and construction of commercial facilities would follow in about two years. According to the producers, this assumes favorable toxicology, successful process research, and strong market interest.

This would be followed by additional time for CFC customers to make the transition and to conduct additional research. CFC customers may be required to redesign processing facilities to address possible increased risks of workplace toxicity or flammability resulting from the use of alternatives. They may also have to retool existing equipment or develop new equipment to accomodate different chemical and physical properties of the foam, i.e., boiling point.

End use product performance must also be assessed. For insulation, this would require studying such things as the aging of the foam, i.e., its retention of its insulating value, and flammability. Actual performance of the product in use over time must be studied to assess the thermal characteristics. Additionally, construction products must be tested to meet building code requirements. Typically, tests for flame spread and smoke generation must be conducted, and other tests such as tests for combustion toxicity may also be required. Qualifying a product for approval by building code authorities can take several years.

(6) In terms of cost and efficiency, how do substitutes compare with chemicals you are using?

At this time, basically we do not know how substitutes would compare in terms of costs and efficiency with the CFCs our industry currently uses. The producers have estimated substitutes would cost at least 2-3 times the current cost. Other than some limited information on the interior insulating capability of CFC-123 we do not have information on the other potential substitutes. This is because they have not been made in quantities necessary for such testing.

Conclusion

SPI supports responsible international action to address environmental concerns regarding stratospheric ozone depletion. We urge Congress to reject extreme action such as that embodied in the pending proposals offered by Senators Baucus and Chafee. If enacted, the economic consequences for our industry would be disastrous. This economic disruption need not occur if industry is allowed sufficient time -- 7 to 10 years -- for the development of substitutes. We ask you to consider the significant value of our products to other important environmental goals such as energy conservation and air quality, and their contribution in making our lives more convenient and comfortable. Lastly, we ask you to realize that the economic impact on our industry of your proposals could cause many of us to lose not only our jobs, but the investment of a lifetime.

Thank you, Mr. Chairman, Senators. I appreciate the invitation to appear before you today and the opportunity to present the views of The Society of the Plastics Industry.

TESTIMONY

OF

DONALD E. HIPCHEN

VICE-PRESIDENT

JIM WALTER CORPORATION

PRESIDENT

JIM WALTER RESEARCH CORP

BEFORE

THE SUBCOMMITTEE ON HAZARDOUS WASTE AND TOXIC SUBSTANCES

AND

THE SUBCOMMITTEE ON ENVIRONMENTAL PROTECTION

OF

UNITED STATES SENATE

COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS

MAY 14, 1987

INTRODUCTION

Mr. Chairman, members of the subcommittees, Jim Walter Corporation appreciates this opportunity to testify on behalf of CFC users in the rigid foam plastic insulation industry.

Jim Walter Corporation is one of the nation's 200 largest industrial companies, offering a diversified line of products and services for residential and non-residential construction, renovation/remodeling, water and waste water transmission, homebuilding, industrial and consumer markets. Annual sales are presently about $2.4 billion.

I am Donald Hipchen, Vice President of Research for Jim Walter Corporation and President of Jim Walter Research Corporation, which is our centralized research organization. My background includes a degree in Chemical Engineering and 25 years of direct scientific involvement in the rigid foam plastics industry.

The Celotex Corporation and Apache Building Products Company are subsidiaries of Jim Walter Corporation involved in building products, including foam insulations. Collectively these subsidiaries make us the world's largest manufacturers of rigid foam insulation. We have been in this business since the mid 1960's and currently have foam insulation sales in excess of $200,000,000 annually. We have nine manufacturing plants in seven states, and over 1,000 employees directly involved in this business. It should be noted that the aggregate United States rigid foam plastic insulation industry, which is dependent upon CFC's, has an annual value of products and services of 2 billion dollars and directly employs 40,000 people.

I am representing this industry as a result of my personal experience, our company's position in the industry and on-going involvement with CFC manufacturers and industry associations such as the Society of Plastics Industry (S.P.I.), the Polyisocyanurate Insulation Manufacturers Association (P.I.M.A.), and the Alliance for Responsible CFC Policy.

In the following paragraphs I will address the identity, history and commercial importance of rigid foam plastic insulations, the eight questions contained in your letter inviting me here, and certain other factors which have great significance to the CFC/ozone situation.

FOAM PLASTIC INSULATIONS-IDENTITY, HISTORY, IMPORTANCE

The rigid foam plastic insulations used widely in the U.S. marketplace today, include polyurethane foam, polyisocyanurate foam, phenolic foam and extruded polystyrene foam. These foam insulations employ CFC's as a blowing or expansion agent which is encapsulated within the foam cells to provide the highest insulating efficiency (resistance to heat flow) of any commercial insulations or other construction material known to man. These products and the technology they employ are not "new". They represent the state-of-the-art in insulation technology which has been evolving over a period of 30 to 40 years - since their earliest development and commercial use in the 1940's and 1950's. The use of CFC's in foam plastic insulations, originated in the 1950's, is almost exclusively responsible for their high insulating efficiency. Foam plastic insulations are 400-600% better insulators than plywood, 200-300% better than wood fiberboard and 150-250% better than fiberglass. In the U.S. by 1985, rigid foam plastic insulations were used in 49% of new residential dwellings and 30% of existing residential dwellings which were reinsulated. They were used in 56% of flat roofs in new commercial buildings, 80% of masonry sidewalls in new commercial buildings, and 42% of new farm buildings. In addition, they were used virtually exclusively in household refrigerators and freezers, commercial walk-in coolers and freezers, and portable coolers. They are also used extensively to insulate pipelines, tanks, solar collectors, fishing trawlers, automobiles, aircraft, etc. Foam plastic insulation technology is the state-of-the-art; after many years of development and use this technology is to energy conservation what the jet aircraft is to transportation or the computer is to data processing.

RESPONSES TO QUESTIONS OF THE SUBCOMMITTEES

Q1. Rigid foam plastic insulations use primarily CFC-11 and CFC-12 (72% and 28% respectively of the total CFC's used in insulating foams). A very small amount of CFC-113 is also used in phenolic foam.

Q2. In polyurethane, polyisocyanurate and phenolic foam technology, the CFC chemicals are mixed as liquids with other liquid chemicals which then chemically react to form a solid foam in a variety of processes depending on the form and end use application of the product.

In extruded polystyrene foam the CFC chemicals are handled as a liquid which is injected and mixed into molten polystyrene in an extrusion process which mechanically forms the polystyrene into a board or sheet and cools it to a solid foam.

In both cases, the CFC chemical is converted in the process, by the effects of heat and pressure release, from a liquid to a gas, which causes the formation of foam, or interconnected closed cells, and this gas is encapsulated within the cells.

Q3. During manufacture of the foams, 85-95% of the CFC's are encapsulated within the foam cells - 5-15% are emitted to the atmosphere. These rates vary within these ranges depending upon the type of foam and the manufacturing process.

The emission rates of CFC's from the foam cells themselves is extremely long. The science is limited in this area since CFC's have only been used about 30 years. However, previous estimates suggest a period in excess of 50 years for full emission from polystyrene foam, and several recent studies indicate emission rates as much as 100 to 300 + years for polyurethane and polyisocyanurate foams. A number of foam insulation products are made as boards with impermeable facings such as aluminum foil. Others are formed in cavities with impermeable surfaces, such as refrigerators. CFC emissions from these materials would occur at even slower rates, or not at all, until the products themselves are destroyed at the end of their life cycle.

Recovery and recycling of the low (5-15%) emissions from the manufacturing processes would not have a significant impact upon possible ozone depletion, since the vast majority of the CFC's used (85-95%) is contained in the product and the end use application. Also, there is no known process technology to recover the low process emissions in many of the process methods employed, e.g. how would containment and recovery be accomplished when foam insulation is sprayed-in-place at the end use site - a pipeline, petroleum or gas storage tank or building under construction? Likewise it is impossible to conceive of containment or recovery of the emissions from the product in the millions of end use sites over a 50+ to 300+ year time period.

Q4. There are no commercially available substitutes for CFC's 11, 12 and 113 which can be used in rigid foam plastic insulations at the present time.

CFC-22, which is commercially available and is considered to have only 1/20 the potential for ozone depletion as CFC-11 and 1/16 that of CFC-12, is being evaluated as a substitute for CFC-12. A number of rigid foam insulation manufacturers, including my own company, are evaluating it as such. However, because of the significantly different properties of CFC-22, considerable work and evaluation remains to be done. Also, it must be noted that if CFC-22 can be used in place of CFC-12 in our industry, this would only be a partial resolution since this industry relies primarily on CFC-11 (72%) and less on CFC-12 (28%).

Q5. There are several CFC chemicals which have been identified as possible substitutes for the primary chemicals now used - CFC-11 and CFC-12, and some have been produced in small quantities. These are considered promising because their chemical structure is such that they would be destroyed after emission into the troposphere and would not reach the stratosphere where ozone depletion is considered a potential problem. These possible substitutes are:

CFC's Presently Available	Potential Substitutes
CFC-11	CFC-123, CFC-123a
CFC-12	CFC-134a

Process technology to manufacture these possible alternates is not presently available but is under development. Obviously, no manufacturing plants are available to make them and only very limited amounts are available. The CFC manufacturers estimate a minimum time period of about 7 years to complete the necessary work, including toxicity testing, and have these potential alternates commercially available. This time estimate is based on the assumption that these alternates will be acceptable for end-use application in rigid foam insulations. The foam insulation manufacturers have begun and will continue to evaluate these alternates as experimental quantities become available. If the alternates are found suitable, and once they become commercially available, it may require perhaps no more than one year to fully incorporate them into rigid foam insulations.

In terms of cost and efficiency of these alternates the available information is not precise. The CFC manufacturers are estimating the costs of potential alternates at 2 to 3 times the present cost of CFC's 11 and 12. This may not prove prohibitive in terms of the effect on cost of foam insulations for most applications, particularly if other economies could be developed in the same time frame. The limited available technology does indicate that the insulating value of the alternates in gaseous form is about 10 to 30% poorer than that of gaseous CFC-11 and 12. However, the effect of this on insulation value and cost of foam insulation is not presently known but is being investigated.

Q6. It is difficult for a single company to know and summarize what has been done since 1978 by all foam industry companies (perhaps 1500 to 2000, including spray foam companies) to encourage development of chemical substitutes. However, beginning in 1979 Jim Walter Research has evaluated well over 100 chemical compounds as possible substitutes -

none even close to suitable were found. At the present time our research in this area exceeds $1,000,000 per year. We are evaluating the alternates discussed in our response to Q5. in conjunction with the CFC manufacturers. Simultaneously we are working with other chemical manufacturers to identify and evaluate other compounds which may offer promise. Many other companies of the foam insulation industry have similar efforts underway.

Q7.8 The questions about substitutes for foam plastic insulations and their cost and efficiency comparisons can be answered simultaneously. A wide variety of materials have been used by mankind as insulation over the years. These include straw, wood, wood chips, corn cobs, sawdust, soil, masonry, etc., which are no longer used or no longer considered as insulators. Earlier in this century, cellulose or wood fiberboard, mineral wool and fiberglass were developed and commercialized as more efficient insulations in most applications requiring insulation. As stated earlier, the evolution of foam plastic insulations with even greater efficiency began in mid-century. In recent years both cellulose fiberboard and mineral wool have diminished in use (although significant amounts are still used in certain applications) as fiberglass and the more efficient foam insulations have became the dominant insulations in use today. This widespread use of fiberglass and foam plastics has evolved simultaneously with rapid growth in the consumption and cost of energy - especially the energy crises of the 1970's. As these changes in insulation and the substantial need for energy conservation were evolving, so also were new methods of construction employing the high efficiency foam insulations to achieve optimum energy conservation at minimum construction cost. For example, in the walls of houses (about 1/2 of new houses employ foam insulations) 3" to 3 1/2" of fiberglass is used to fill the cavity between 3 1/2" (nominally 4") wall studs and 1/2" to 1" of foam insulation is installed on the exterior of the wall studs to meet modern building code insulation requirements. Neither fiberglass nor any other non-foam insulation can simply be substituted for the high efficiency foam insulation in this modern method of construction without increasing energy consumption (less insulation) or increasing wall thickness at markedly increased construction cost (nominal 6" studs would be required and all window frames, door frames, etc. would have to be widened). Similarly, the flat roofs on new commercial buildings (56+% use foam) are designed for lower structural loads due to the use of the light-weight high efficiency foam insulations. In older commercial buildings many flat roofs can be reinsulated by installing foam insulation and a new roof over the old roof - avoiding the cost of removing the old roof and/or increasing the strength of the structural framework. In refrigeration - refrigerators, freezers, walk-in coolers and freezers, truck trailers, railcars, etc. - foam insulations are used almost exclusively to achieve not only energy conservation but also thin walls, maximum interior space and structural strength. The use of non-foam insulations here would reduce storage space, increase weight and reduce payloads, increase the use of structural material and increase energy consumption - all with attendent increased costs of manufacture and operation.

In summary, high efficiency, light-weight foam insulations and the manufacturing and construction methods to use them have been evolving over a 30-40 year period. They impact virtually everyone, as does the telephone, automobile, computers, etc. There are no viable substitute insulations without great penalties. If foam insulations were to be eliminated from existance through the premature and perhaps unnecessary elimination of CFC's the increase in energy consumption and economic effects on society would be staggering.

CFC'S AND THE OZONE LAYER-AN APPRAISAL OF THE SCIENCE

Volumes of information have been published about the science of CFC's (and other chemical compounds) and the ozone layer. An exhaustive review is not necessary here but a synopsis is appropriate. The following are key elements of the science as it is known today:

1. Modern attention and the increased activity on ozone science began in 1974 - only 13 years ago. Much has been learned since then and knowledge is improving daily, however, much remains to be learned and years will be required.

2. Analyses of the longest running (25 to 30 years) continuous set of actual ozone measurements show there has been no persistent change to date in the total amount of ozone.

3. Science has observed that the total amount of ozone over the Antartic continent has decreased significantly during successive Octobers (not year round) since the mid 1970's. The decrease cannot be explained based on current knowledge of atmospheric processes.

4. In 1979, model calculations reported by the National Academy of Sciences predicted decreases in total ozone in more than 100 years as high as 16.5 to 18.6%. As a result of increased scientific knowledge (reaction rate chemistry, etc.) model calculations of 1982 to 1984 predicted decreases in total ozone in more than 100 years at much lower values- 5 to 7% (based on a hypothetical case of continuing release of CFC's at 1980 rates). Continued scientific research will reduce uncertainties and provide better tools for forecasting ozone amounts. However, years of research will be required to provide accurate 100 year forecasts.

5. At current CFC consumption levels, when emissions of CFC's and other trace gases (methane, nitrous oxide, carbon dioxide, etc.) are taken together, scientific model calculations suggest little change in total global ozone over the next few decades. Longer term calculations, greater than 50 years, do predict ozone decreases but only for substantially compounded increases in CFC emissions over the period.

WHAT INDUSTRY IS DOING

Contrary to some suggestions in the media that industry has ignored the CFC/ozone issue and is sacrificing the ozone layer for profits, industry has been active and responsible. It should be noted that:

1. Industry, through the Chemical Manufacturers Association has expended approximately $20,000,000 on tropospheric and stratospheric measurements of ozone and other trace chemicals, in laboratory studies related to atmospheric measurements, in investigation of reaction rate chemistry and modeling, and on other related projects. This effort is continuing.

2. In spite of the as-yet uncertain scientific knowledge, industry has initiated the development and evaluation of non-ozone sensitive alternates to the present commercial CFC's. It is estimated that tens of millions of dollars have been spent already.

3. Industry has accepted and supported the unilateral ban in the United States (1978) on use of CFC's in aerosol applications.

4. Industry itself has raised the issue of potential significant ozone depletion in the 50 to 100 year time frame if excessive growth of CFC's is allowed.

5. Industry supports prudent action and the efforts of the Environmental Protection Agency and The State Department working with the

UN Environmental Programme to achieve international limits on the rate of growth of CFC production and/or emissions.

6. Industry does not support a phase-out of the use of CFC's. The present scientific knowledge and model calculations simply do not indicate the need to consider this at the present time. There is substantial time to improve scientific knowledge and to pursue the development of alternates before such action would be required - if at all.

7. Industry does not support unilateral action in the United States. This would not resolve the potential for ozone depletion which is a global problem.

8. Industry does not support surtaxes or any financial penalties on the use of CFC's to reduce their consumption. This cost would become an unnecessary burden upon the end use consumer and would bring about significantly lower usage of end products (especially foam plastic insulations). The latter effect would result in substantial increases in energy consumption and a substantial increase in construction costs, as well as significant loss of American jobs.

CFC'S IN AEROSOLS VS. OTHER USES-GLOBAL BASIS

The ozone depletion theory was initiated in 1974. In 1978 unilateral action was taken in the United States to ban the use of CFC's in non-essential aerosol applications. Prior to 1978 use of CFC's in aerosols in the U.S. was widespread. Aerosol use of CFC's remains widespread in the rest of the world today.

Discontinuation of the widespread use of CFC's in aerosols in the U.S. in 1978 was rapid and had minimal economic effects, as acceptable and less expensive substitutes were readily available.

Table I shows that aerosol use of CFC's in the U.S. is only 4.4% of total uses, whereas worldwide (including the U.S.) aerosols are 31.5% of total uses. Table II shows that if worldwide use in aerosols were reduced to the U.S. level of 4.4%, a net reduction of 27% in total worldwide consumption would result.

TABLE I (1)

1985 Estimated Use of CFC-11 and CFC-12

	CFC-11 MM lbs.	CFC-12 MM lbs.	Total MM lbs.	Aerosol as % of All Uses
U.S.: Aerosol Use (2)	8.3	11.9	20.2	4.4
U.S.: All Uses (2)	165.4	297.6	463.0	
World: Aerosol Use	205.1	257.5	462.6	31.5
World: All Uses	661.5	804.8	1,446.3	

TABLE II

1985 Estimated Use of CFC-11 and CFC-12 if World Use of CFC's in Aerosols are Restricted as in the U.S.

	Total MM lbs.	Aerosol as % of All Uses
World: Aerosol Use (2)	46.2	4.4
World: All Uses (2)	1,049.9	

Net Reduction: 396.4 MM lbs. or 27.4%

(1) Data from Hammitt, J. K. et al, "Product Uses and Market Trends for Potential Ozone-Depleting Substances 1985-2000", RAND, May, 1986.

(2) Including the United States.

If a cap on total production and use of CFC's is effected without addressing the disparity of aerosol usage, the economic effects on U.S. industry and consumers will be immediate. Growth of essential and important end use applications will cease, the risk of rising CFC prices and thus, product prices (e.g. foam plastic insulations) will be high and end-use applications will vie for the available supply with certain cost sensitive applications (especially foam plastic insulations) subject to greater economic pressures and lower usage. However, the remainder of the world will be able to gradually convert from CFC's to hydrocarbons in aerosols and allow other applications to grow. In effect, countries other than the U.S. will use their high use in aerosols as a "bank" to sustain growth in other applications, while growth in these applications in the U.S. will stop. This would result in higher costs, loss of jobs, etc. in the U.S. with no similar effect in other countries. It could result in greater imports of CFC containing products into the U.S. from the remainder of the world.

If a partial or near total phase-out of CFC use were to be effected, the economic effects in the U.S. would be devastating with even the first incremental reduction. The effects in other countries would be delayed until the phase-out and demand for CFC's in other applications exhausted the "bank" of CFC's available from aerosol use reduction.

Serious consideration should be given to negotiating a world-wide reduction in aerosol use - similar to that in the U.S. either before or in conjunction with a limit or cap on world-wide CFC use.

SUMMARY AND RECOMMENDATIONS

1. Rigid foam plastic insulations have evolved over 30 to 40 years as the most efficient insulations known to man. They are in widespread use in houses, buildings, appliances, transportation, food, chemical and petroleum storage, etc. They are contributing substantially to energy conservation and lower costs where used. They are totally dependent upon CFC's 11 and 12 for their performance properties. The elimination of CFC's or even partial phase-out would have staggering effects on the economy, jobs and energy conservation.

2. There are no commercially available substitutes for CFC's 11 and 12. Several substitutes have been identified which offer promise. If successful, it will require at least 7 to 10 years to fully implement their use.

3. There is substantial time to develop the necessary scientific knowledge about effects on the ozone layer and for government and industry to react, if necessary. Ozone measurements show no persistent change in the 13 years since the issue was raised. Model calculations suggest little change in total global ozone over the next few decades (20 to 30 years). Longer term calculations, greater than 50 years, do predict ozone decreases but only for substantially compounded increases in CFC emissions over that period.

4. In view of this possibility, industry believes it would be prudent to limit growth of CFC's. No unilateral action should be taken by the

United States. This potential problem is global in nature and unilateral action would only have serious effects on the U.S. economy without providing a resolution to the possible problem. A world-wide reduction in aerosal use of CFC's, consistent with that already accomplished in the U.S., should be negotiated before or in conjunction with a limit on CFC growth.

NRG BARRIERS, INC.
61 Emery Street
Sanford, ME 04073
(207) 324 7745

STATEMENT

OF

WILLIAM S. JELIN

PRESIDENT

NRG BARRIERS, INC

TO

JOINT HEARING OF SENATE SUBCOMMITTEE ON
ENVIRONMENTAL PROTECTION AND SUBCOMMITTEE ON
HAZARDOUS WASTES AND TOXIC SUBSTANCES

May 14, 1987

NRG
BARRIERS

Mr. Chairman and members of the Committee, my name is William Jelin. I am the President and Chief Executive Officer of NRG Barriers, Inc.

NRG is a manufacturer of polyisocyanurate foam roof insulation. We have two plants, one in Sanford, Maine, and the other in Hazleton, Pennsylvania. We have been in this business since 1975, and I like to think that we have been modestly successful. Certainly, there has been considerable demand for the product. Consumers with an interest in energy conservation obviously like it.

I do not apprear here today in opposition to the efforts of the United States government to regulate and ultimately eliminate the use of CFCs. Rather, I am here today to provide you with the perspective of a small businessperson.

You have heard, and I am sure you will hear again, from the giants of the American Chemical Industry. I am here because I want you to know what will happen to a small family-owned company if the limitations on production contained in S. 570 and S. 571 are enacted into law by the Congress or promulgated by administrative regulation. Very simply, we'll be out of business.

I am not opposed to control and eventual phase out because, frankly, I personally believe that if something is damaging to our environment, we must find a substitute that will eliminate the problem.

I think I am as sensitive to this issue as anyone. For 20 years, I have been a member of the Sierra Club, and I have participated in the Sierra Club's efforts to preserve and protect our environment. I am a native of New Jersey, and for many years I have been quite active with New Jersey Environmental Lobby. In my hometown of Kennebunkport, Maine, I have been a member of, and have worked closely with, groups who have sought to protect environmentally sensitive areas of our beautiful

State. In fact, I was one of the founders of the Laudholm Farm Trust, which was one of the first organizations formed after passage of the Estuarine Protection Act, which encouraged the conservation the conservation of unique and environmentally-sensitive estaurine areas. Our organization, the Laudholm Farm, is the owner and conservator of 500 acres of estuarine land which compromises an important part of the Rachel Carson National Wildlife Preserve.

In addition, I am a member of the New England Council's environmental study committee.

I am also proud of the fact that for 12 years my company has manufactured the most thermally efficient insulation known to man. During the period of energy crisis beginning in the mid-1970's, my company made an important qualitative and quantitative contribution to the effort to reduce energy waste and to reduce America's reliance on fossil fuels.

NRG
BARRIERS

Lest we forget, it should be remembered that not very long ago energy conservation was regarded as a high priority objective by environmental groups and, indeed, the Congress. And in this context, we were pleased that we were in a business that made a real difference in conserving natural resources.

I also want to add, because I am particularly proud of this, that we are one of the few companies that has chosen to obtain all of our polyol requirements from recycled soft drink bottles, photographic film scrap or other waste plastic products. We do this not because it's the cheapest method -- it's not -- but because it makes environmental sense. As anyone who listened, this week to Jane Pauley's interview with the Governor of my native state of New Jersey, Tom Kean knows, the disposal of these soft drink bottles is New Jersey's most pernicious environmental problem.

Nevertheless, we understand that the process used to manufacturer our product may be, in itself, an environmental problem. Our product utilized CFC 11, which is used as a blowing agent in the manufacture of plastic foam. The CFC gasses are trapped in each tiny bubble of the foam, and because CFC gases are such poor conductors of heat compared with other gasses, the CFC actually creates the insulation value of the foam. I think every expert would tell you that foams made with CFCs are the best insulation that American technology currently offers to consumers who have an interest in conserving energy.

Incidentally, one of the reasons why the CFC gas is so effective for insulating purposes is that it remains trapped in the foam for a very long time. And this, I think, is quite relevant to your scientific inquiry into how the escape of these gasses into the stratosphere may break down the ozone layer. In insulated foam products, there may be up to a 10% loss in CFC gasses in the first 2 years, but there is some evidence that thereafter there is an equilibrium created between the internally generated pressure of the CFC gas and external atmospheric pressure which inhibits any further emissions.

Moreover, scientific evidence shows that half the CFC gasses are retained in the cellular structure of the foam for at least 99 years. This is good news for our customers, and also good news for those, like myself, who are concerned with CFC emissions.

However, I am not here to debate the scientific issues. I am not chemist, and my company is not big enough to engage in the kind of research and development which must find an answer to this problem.

And that brings me to the crux of my testimony. As a small businessperson, I am not in a position to develop chemical substitutes for CFCs. Stated another way: I am really at the mercy of my suppliers to develop an economically viable substitute. And if they *don't* develop such a substitute, and you *do* enact legislation similar to S. 570 or

S. 571, then I'm out of business.

If, in fact, this is a life or death situation for my small company, then what, you might ask, are we doing about it.

Well, chemical vendors never come to our office without being subjected to some very strong comments from us on why they have not developed an economically viable substitute. And at every industry conference that I go to, I continually raise the issue of chemical substitutes with my colleagues, with suppliers, and with anyone else that will listen. Hardly a week goes by without my undertaking to discuss this issue with people involved in my industry. As a consumer, I tell suppliers that I am going to do business with whichever supplier is working the hardest to find a substitute. Unfortunately, this is all I can do. The development of a substitute is beyond my company's control.

NRG
BARRIERS

Based upon my layman's analysis of the evidence, it appears that the only area of CFC use where there is no know chemical substitutes is in the manufacture of polyisocyanurate foam insulation. There seems to be some real possibility of substitutes in other use areas in the near term. And at least in one case, fast food containers, it would appear that the product itself need not be made with CFC blowing agents. But in our case, it is the essence of the product. And there is no other effective way to make foam insulation.

Some, including EPA, have suggested that we can obtain the same level of insulation value by using CFC 123. However, the viability and effectiveness of CFC 123 has not been commercially demonstrated because it has just become available, in sample form. Yet, every expert tells us that this would result in a 30-40% reduction of R value, and at the same time require the use of considerably more building materials. That, Mr. Chairman and members of the Committee, is not an economically viable alternative. What they are really suggesting is that we should go into another business that does the job more poorly that we do it now. Given my predicament, and I suggest the predicament of other small businesses which manufacture foam insulation panels, we must oppose either legislation or regulations which reduce CFC usage in our industry on a phase-out basis beginning January 1, 1989. One thing is clear: there will not be a commercially viable alternative for our industry by that date.

However, I think we can live with a feeze on 1986 production levels, which is in compliance with the latest international agreement. I also think that it might be reasonable to contemplate an extended extended phase-out which begins later than 1990.

In summary, I hope you will consider the fact that for at least some users of CFCs -- specifically, the foam insulation manufacturers - there appears to be no realistic alternative in the near term. I hope you will also consider that it appears that the quantitative contribution of our particular group of users to CFC emissions is not significant in terms of the overall impact on the ozone layer. Therefore, it makes a good deal of sense for the Congress, at the very least, to permit utilization of CFCs by the foam insulation industry at present levels until the mid-1990's when, hopefully, our suppliers will have developed a commercially viable substitute.

To do otherwise is to put the foam insulation industry out of business. And in the case of small undiversified companies, such as my own, to just plain bankrupt us.

I would be happy to consult further with members of the Committee on this issue, and to discuss my small businessman's perspective on the issue with members of your staff whenever they wish. I intend to be a frequent visitor to Washington as you consider this issue, because our very existence depends upon the outcome of your deliberations.

Thank you for allowing me this opportunity.

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BARRIERS

STATEMENT

OF

Michael H. Levy
Manager, Environmental Legislative & Regulatory Affairs
MOBIL CHEMICAL COMPANY

TO

JOINT SUBCOMMITTEES ON ENVIRONMENTAL PROTECTION
AND HAZARDOUS WASTE AND TOXIC SUBSTANCES
U. S. SENATE
Washington, D. C.

ON

CFCs (CHLOROFLUOROCARBONS) AND STRATOSPHERIC OZONE

May 14, 1987

Senator Baucus, Senator Mitchell, Subcommittee members, Mobil Chemical appreciates this opportunity to present its testimony on the subject of polystyrene foam manufacturing blowing agent alternatives as they relate to CFC's (chlorofluorocarbons) and stratospheric ozone.

Mobil Chemical Company is an operating division of Mobil Corporation, with annual sales of nearly $2.3 billion in 1986.

We are the world's leading producer of disposable plastics products. We manufacture stretch film, plastic grocery sacks, trash bags, food bags, and foam products such as food trays, egg cartons, disposable dinnerware, and hinged lid containers.

We use extremely small quantities of CFC's - chlorofluorocarbons - in only a small amount of the foam products we manufacture. CFC-12 is costly. The reason we use CFC-12 at all is that it imparts certain desirable quality features to some foam products. Mobil Chemical Company pioneered the technology using a lower cost hydrocarbon alternative to CFC-12 as a blowing agent - isopentane. In addition, our company has an aggressive research and development effort that has resulted in the use of an isopentane/carbon dioxide blowing agent mixture that reduces isopentane emissions.

In order to make a rigid foam container, polystyrene has to be converted to a lightweight, insulating, rigid, cellular material. This is done by mixing a blowing agent with nucleating agents and the polystyrene resin in an extrusion operation.

Mobil Chemical Company has five major polystyrene foam manufacturing facilities in the U.S. that produce finished polystyrene foam products. These plants are located in Bakersfield, California; Canandaigua, New York; Covington, Georgia; Frankfort, Illinois; and Temple, Texas.

Mobil Chemical Company uses three different blowing agents in these plants:

- Commercial CFC-12
- Isopentane (a hydrocarbon which in some areas contributes to smog)
- Isopentane/carbon dioxide blend (reduces hydrocarbon emissions)

In four of our five polystyrene foam plants, less than 10% of the production is made using CFC-12. In the fifth and smallest plant, CFC-12 is used as the only blowing agent because of area emission control requirements which have precluded the use of isopentane. We are, however, attempting to work out an operating agreement with EPA which would include a shift from CFC-12 to isopentane, installation of an incinerator, and a resulting reduction of the isopentane emissions.

The quantities of blowing agent emissions from our plants are relatively small. The amount of blowing agent used in the extrusion process itself ranges from 3-5% of the product weight, and about half of the blowing agent used in the process remains in the final product. The in-plant emissions released to the air are of very low concentration, and are highly diluted.

Selection of a blowing agent is dependent upon the desired properties of the product to be produced, and such technical criteria as vapor pressure, solubility in the molten polymer, plasticizing effect and storage and handling requirements. Cost and availability are, of course, very important since this is a highly competitive industry.

Mobil Chemical Company has been able to achieve up to a 25% reduction of isopentane used in certain product lines that are made with an isopentane/carbon dioxide blend of blowing agent at our facilities. Product quality considerations such as surface smoothness, essential for the rendering of high quality printing or embossing on finished products, are an obstacle to increasing the replacement of isopentane with carbon dioxide.

By developing the isopentane/carbon dioxide blend, we have significantly reduced isopentane emissions from our process. We have thus far spent between $3-4 million in research and development costs on this project. This technology is a cost-effective alternative to the incinerators we have had to install at some of our foams plants (at a capital cost between $1.0-1.5 million each, and high operating costs), and reinforces our company's commitment to further reduce emissions with alternatives that do not affect stratospheric ozone. We are experimenting with greater use of carbon dioxide in the blowing agent mixture, but, thus far, have not found a way to maintain the same quality standards of the products we now make.

In summary, a ban on CFC-12 used by all manufacturers would have minimum impact on our polystyrene foam business. In the interest of doing what's effective to improve the environment, Mobil Chemical is continuing its efforts to increase the use of non-polluting blowing agents.

Thank you for the opportunity to appear before you today. I will be happy to respond to any questions you may have.

Dolco
Packaging

STATEMENT

OF

JOHN W. BUFFINGTON

CHAIRMAN OF THE BOARD

DOLCO PACKAGING CORP.

TO

THE SENATE SUBCOMMITTEE ON HAZARDOUS WASTES
AND TOXIC SUBSTANCES AND
THE SENATE SUBCOMMITTEE ON ENVIRONMENTAL PROTECTION

JOINT HEARINGS ON
STRATOSPHERIC OZONE DEPLETION
AND SUBSTITUTES FOR OZONE DEPLETING CHEMICALS

May 20, 1987

Executive Offices
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Mr. Chairmen and Members of the Subcommittees, my name is John W. Buffington. I am the Chairman of the Board and Chief Executive Office of Dolco Packaging Corp. (DOLCO).

DOLCO is a manufacturer of foam plastic single service food containers. We operate in an industry which accounts for only 1% of the CFCs used in the U.S. DOLCO has five major manufacturing plants located in Pico Rivera, California; Lawrenceville, Georgia; Decatur, Indiana; Dallas, Texas; and Wenatchee, Washington. Annual sales are $63,000,000 and total employees are 800. DOLCO produces safe, sanitary, strong, and well insulated packaging materials for the food industry. DOLCO also provides jobs in several small towns which do not otherwise have much industry (Decatur, Lawrenceville and Wenatchee).

All of DOLCO's products utilize CFC-12 as a blowing agent; a very small usage as noted above. We understand that Congress and/or the EPA are about to regulate CFCs with a view toward eliminating or drastically-reducing them. This would have the effect of driving DOLCO out of business. And yet there is not 100% agreement among the scientific community that CFCs must be reduced or eliminated. The only position that seems to have universal agreement is that CFCs should not be allowed to increase in an uncontrolled manner.

The only immediate solution/substitute for DOLCO not to use any CFCs would be to convert its plants to using pentane, a highly flammable and explosive substance with pollution problems of its own. Safety for our employees is a foremost concern. The cost of conversion is approximately $1,000,000 per plant or $5,000,000 in total, which represents a capital expenditure not economically feasible to DOLCO. Also, with other environmental concerns, it would be very difficult to obtain state regulatory permission to utilize pentane.

In foam packaging, an excellent potential substitute for CFC-12 is CFC-22. We understand that this product is undergoing further testing and does not yet have FDA approval for uses in food packaging. CFC-22, although it is a CFC, does not as we understand it pose any substantial threat to the ozone layer. It contains only one-twentieth (1/20) of the ozone depletion potential of CFC-12. Dolco could convert to using CFC-22 very quickly and economically. Accordingly, if Congress decides to regulate CFC-12, we urge the speedy approval of CFC-22 as a substitute for use in food packaging products.

Ms. Claussen's statement (on behalf of the EPA) that plastic food packaging could be replaced by paper packaging should be weighed very carefully before acted upon. You would be eliminating an industry and many jobs and yet not affecting the usage of CFCs in any appreciable manner. Plastic food packaging has very desirable attributes over paper including superior insulation and protection, and it is sterile, sanitary, non-toxic, and non-moisture absorbing. Our products do not contain potentially contaminating glues or special coatings as do some paper packaging products. In short, we provide a beneficial product to society. DOLCO cannot convert to producing paper products.

DOLCO is a relatively small company which is only a part of an industry which makes a very small usage of CFCs (1% by EPA estimates). Rather than regulate DOLCO out of business, we ask that Congress exempt small businesses making such small uses of CFCs. Such exemption should be considered against the background of the near-term solution of CFC-22 and the long term solution of F-134a which should be available within the timetable for reduction of CFCs by international agreements. Further, DOLCO would urge Congress to encourage further scientific study on the ozone layer, any depletion thereof, the exact causes of the depletion, and all solutions to such depletion.

We thank you for your consideration of our statement. The livelihood of our company and our 800 employees depends on the actions taken by Congress on this subject.

JWBuffington

John W. Buffington

health industry
manufacturers
association **hima**

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June 1, 1987

The Honorable Max S. Baucus
United States Senate
Senate Hart Building, Room 706
Washington, D.C. 20510

Dear Senator Baucus:

The Health Industry Manufacturers Association (HIMA) wishes to submit the enclosed report -- Chlorofluorocarbons: 1981 Submission to the Environmental Protection Agency, which details our industry's use of chlorofluorocarbons (CFCs)-- for the record of hearings held on this issue May 14, 1987, by the Subcommittee on Hazardous Wastes and Toxic Substances. HIMA is interested in seeking an exemption for all medical product uses of CFCs from any potential regulation.

For your background, HIMA is the national trade association representing over 300 manufacturers of medical devices, diagnostics, and health information systems products. HIMA member company products span the entire spectrum of medical technology from tongue depressors to sophisticated life-saving equipment. Our industry consists mainly of small businesses which use CFCs in a variety of ways in the manufacture of products which serve the United States health care system. Substitute chemicals are not readily available and would result in safety concerns and increased costs of many health care products.

In 1981, HIMA commented on proposed legislative and regulatory activities to limit the availability of CFCs. HIMA provided comprehensive comments to the Environmental Protection Agency on its proposed rule to cap CFC production. That same year, we also submitted comments on this issue into the record of hearings held by the Senate Subcommittee on Toxic Substances and Environmental Oversight.

As discussed in the enclosed comments, our industry uses CFCs in two ways - 1) as part of a medical device [usually as an aerosol propellant, a use for which our industry currently must obtain an exemption from the Food and Drug Administration (FDA)], and 2) in the production of medical devices. In the latter case, CFCs are used extensively as a diluent for ethylene oxide sterilization, a process that is used to sterilize approximately 12 billion health care items annually. CFCs are also used as cleaning and degreasing agents for medical products since they volatilize readily and do not leave residues that could jeopardize product safety.

We wish to emphasize a few major points for the Subcommittee's consideration:

- The medical products industry uses only a small percentage of the annual CFC production.
- Substitute chemicals are not readily available. Substitute chemicals must first be studied for any potential hazardous health effects. If these are introduced, they may result in product safety concerns due to residues remaining on the product. This will necessitate extensive testing of the substitute and any potential effects of product residues. The introduction and testing of substitute chemicals could result in increased product costs.
- Current legislative proposals (S. 570 and S. 571) would exempt from restrictions medical device and diagnostic product uses of CFCs deemed essential by the FDA. However, it is unclear whether this exemption applies to CFCs in products (such an exemption is already available from the FDA) as well as to CFCs used in the manufacture of medical products. If the latter is not included in the exemption, our industry's continued use of these chemicals will be severely jeopardized.

  For example, as quantities of available CFCs decrease, prices will rise. As the price rises, the medical products industry will have to pay more for the CFCs it uses. The increased cost will greatly affect our industry since substitute chemicals are not readily available and the majority of medical product manufacturers are small businesses. In this age of health care cost containment, it will be difficult for manufacturers to pass along the cost of such regulation.
- We request that all medical product uses of CFCs -- both within products and in product manufacture -- be exempt from regulation. This may necessitate separating the amount of CFCs used in our industry from the total U.S. production when determining production limitations.

In closing, we hope the Subcommittee will consider the importance of any potential CFC legislation on the medical products industry, a critical component of the United States health care system.

Thank you for this opportunity to submit our comments and please contact us if you have any questions.

Sincerely,

Gerald R.Connor
Vice President, Legislative Affairs

Enclosure

BEFORE THE
UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY

OZONE-DEPLETING CHLOROFLUOROCARBONS; PROPOSED PRODUCTION RESTRICTION: ADVANCE NOTICE OF PROPOSED RULEMAKING. 45 Fed. Reg. 66726 (October 7, 1980)	40 C.F.R. Part 762 OPTS-62009

COMMENTS OF THE HEALTH INDUSTRY MANUFACTURERS ASSOCIATION

March 11, 1981

To Be Published by the Health Industry
Manufacturers Association as
HIMA Report No. 81-2, Chlorofluorocarbons

[NOTE: The following has been excerpted from the above named document. The document, in its entirety, has been retained in committee files.]

PREFACE

The Health Industry Manufacturers Association, in these comments on proposed government regulations that would limit production of chlorofluorocarbons, strongly objects to the proposal and urges the Environmental Protection Agency to withdraw its Advance Notice of Proposed Rulemaking.

Our principal justification for this recommendation is that the scientific theory upon which the Agency bases the proposed regulation is speculative in that (1) the hypothesis of ozone depletion by chlorofluorocarbons may not be true, and (2) even if true, the extent of depletion and the assumed resulting hazards may not occur.

The above view is widely held, even within the Environmental Protection Agency. A September 10, 1980 memorandum from the Assistant Administrator for Pesticides and Toxic Substances to the Administrator recommending approval of the ANPR states:

> "The decision to initiate additional regulation of CFCs without experimental proof of the ozone-depletion theory presents an important question regarding the Agency's authority and willingness to take action despite uncertainty. The decision of the Agency to initiate further regulation to address the as yet unproven risk of ozone depletion despite the apparent lack of such a determination abroad (particularly in Western Europe) is a closely related issue."

A. INTRODUCTION

The Health Industry Manufacturers Association (HIMA) is a Washington-based trade association representing 253 corporations engaged in the manufacture of medical devices and diagnostic products. The majority of HIMA members are small businesses. HIMA is pleased to submit comments to the Environmental Protection Agency (EPA) outlining our evaluation of the Advanced Notice of Proposed Rulemaking (ANPR) pertaining to chlorofluorocarbons (CFCs) published October 7, 1980. (45 Fed. Reg. 66726.)

Our comments on the ANPR are provided because EPA's proposed activity would impact many of our members who depend upon CFCs for the manufacture of medical devices and diagnostic products.

The comments submitted herein include an explanation of how CFCs are used by the medical devices and diagnostic products industry, comments and evaluations of major significance to our industry, and recommendations regarding the ANPR.

B. EXECUTIVE SUMMARY

On behalf of the medical device and diagnostic products industry:

- HIMA presents these comments on EPA's October 7, 1980 ANPR on CFCs.

- HIMA presents, in capsule form, the uses of CFCs by the medical device and diagnostic products industry; explains why substitute chemicals and/or alternatives to the use of CFCs are not available to the nation's health care systems; and details briefly the essential nature of our products.

- HIMA reports to the EPA thirteen specific evaluations of the ANPR, each of which would be adequate cause not to continue with the regulation as presently proposed. Cumulatively, these evaluations clearly justify the recommendations made by the Association.

- HIMA concludes with the recommendations that EPA (1) withdraw the ANPR, (2) sponsor investigations of the CFC depletion theory and the development of adequate non-depleting substitutes, and (3) perform continued ozone trend analyses as an early warning system for any alleged ozone depletion. Should a regulation issue in spite of these recommendations, HIMA requests an exemption for the medical uses of CFCs.

I. HIMA'S RECOMMENDATIONS REGARDING THE ANPR

1. Withdraw the ANPR

In light of the above, we propose that the best interest of the American public and the medical device industry will be served if the EPA withdraws the ANPR. Justification for this action is included in our evaluations. We do not believe that the American public, the Congress, nor industry should be forced to suffer the real consequences of the proposed regulation, which is based on a scientifically disputed theory of CFC-caused ozone depletion and unsubstantiated theories of subsequent damage. Even if the theories are true, coordinated international action to protect the world's biosphere will occur only following the development of adequate non-controversial scientific facts.

2. Sponsor Adequate Scientific Investigations

After withdrawal of the ANPR, the Agency should spearhead an international cooperative effort to investigate the validity of the ozone depletion theory by means in addition to computer models. It will be necessary to base the effort in part on actual measurements of ozone in the stratosphere over time.

In anticipation that there will be international acceptance of the risk of continued CFC use, EPA should also promulgate and/or encourage research in the development of alternative chemicals and/or processes that will be adequate substitutes for present CFC applications.

3. Exemptions for Medical Product Uses

If some further regulation of CFCs issues in spite of the above recommendations, HIMA requests that EPA exempt health care uses of CFCs and take steps to ensure an adequate supply to the health care industry at non-inflated prices.

The Mineral Insulation Manufacturers Association (MIMA) represents companies who manufacture fiber glass, rock wool and slag wool insulation products. These products are used primarily for thermal and sound control in building construction.

Most manufacturers make a range of products depending on the end use requirements for each application. The three major forms of mineral fiber insulation are batt/blanket, loose-fill, and board. Batts are normally placed into framing cavities. Loose-fill is typically pneumatically installed in residential attics. Semi-rigid boards are generally applied to wall or ceiling surfaces. For residential construction, mineral fiber thermal insulation is installed in all construction elements including ceilings, walls, floors, slabs, crawl space walls, and basement walls. A sample of member company product literature is enclosed.

Insulation is installed for a variety of reasons including the need to meet project specifications or energy codes. Energy codes do not stipulate the type of insulation, but establish a performance level that the ceiling, wall, or floor assembly would have to meet. Mineral fiber products can be used exclusively to meet energy code provisions for thermal protection.

Energy codes also have provisions that allow for tradeoffs between ceilings, walls, and floors. For example, if the designer chooses to not meet the wall requirement, he must compensate by increasing the performance of the other elements in the building, such as ceilings and floors. This flexibility allows the designer to make choices on the form of construction and the types of materials used for the project.

The performance of mineral fiber products varies from manufacturer to manufacturer. The table below, however, gives the typical ranges of R values per inch for each major form of insulation.

MINERAL FIBER INSULATION

Form	R/Inch	Typical Product	
		R-Value	Thickness (Inches)
Batt/Blanket	3.0 - 3.7	19	5 1/2 - 6 1/2"
Loose-Fill	2.2 - 2.9	30	10 1/4 - 13 3/4"
Board	3.7 - 4.4	8.7	2"

I have attached two Mineral Insulation Manufacturer's Association publications that address the performance of mineral wool insulation products. The first entitled A Guide to Superior Energy Efficiency in Homes shows on pages 9 through 21 the application of products in various residential construction elements. Facts About Mineral Fiber briefly covers the history of mineral fiber and its characteristics and properties.

Tim Grether
Chairman, State & Local Affairs Committee
Mineral Insulation Manufacturer's Association

TCG/kaw

MEMORANDUM

TO: Hon. Max Baucus
United States Senator from Montana
Subcommittee on Hazardous Waste
and Toxic Substances
Committee on Environment and Public Works
United States Senate
Washington, DC

FROM: Thomas M. Ward ✓
3417 Merrick Drive
Lexington, KY 40502
Telephone: (606) 266-8617 and (606) 268-0202

RE: Hearings on Ozone Depletion
Greenhouse Effect, and Climate Change

DATE: May 22, 1987

I am associated with Mr. W.C. Brown of Lexington, Kentucky who holds national marketing rights to the Adams' Mechanical Condenser Subcooler (AMCS). This device requires approximately one-half the normal refrigerant charge. We are bringing the AMCS to your attention at this time because of our awareness of your efforts, and that of others in the Congress, to find a solution to the urgent problems associated with ozone depletion and the greenhouse effect.

It is our understanding that some 30% to 35% of upper atmospheric pollutants are caused by emissions from various refrigerants that are required to "charge" air conditioning and refrigerating equipment. The AMCS, by requiring an average of 50% less refrigerant, offers a substantial and virtually immediate solution to this problem.

What The AMCS Does

While reducing the refrigerant level in the system to approximately 50% of the normal charge, the AMCS maintains a pure liquid head to the evaporator. This creates several side effects, all of which are good.

1. Operating (head) pressure is greatly reduced. This means that the compressor operates under much less strain. Also, the likelihood of leaks is reduced. Should a leak occur, only half the normal amount of refrigerant would be lost.

2. The amp draw (and the power consumption and demand) of the compressor is reduced by 15% to 25% and run time is reduced 10% to 20%. This results in a proportionate drop in electric cost.
3. Liquid will no longer "stack" in the lower portion of the

condenser coil, thereby making the condenser more efficient.

4. Providing a solid liquid head to the evaporator, with no flash gas, increases capacity by an average of 10%.

The net result is that reduced amperage draw and reduced run time (because of greater capacity) produce overall energy savings of 20% to 30%. This is all accomplished through a stationary design, which means the AMCS has no moving parts, requires no maintenance, and should last for the life of the equipment on which it is installed.

The AMCS Is Recommended For

1. Refrigeration systems (single load, self-contained, multi-evaporation or multiplex).

2. Air conditioning equipment.
3. Refrigerated transport vehicles.
4. Most other fluorocarbon systems using direct expansion (DX) cooling.

A typical AMCS unit is about one foot long and 3-4 inches in diameter. It can be installed during manufacture or retrofitted on existing equipment. Smaller AMCS units are available for installation on automobile air conditioners, either at the point of manufacture or retrofitted on existing equipment. The AMCS is priced to meet the economic feasibility requirements of the industry. Typical payback of cost of unit, including installation, on existing equipment is one to three years. This payback is based on energy savings.

The AMCS Is Not Recommended For

1. Heat Pumps
2. Shaved ice machines
3. Chillers

Examples of successful utilization of the AMCS are

1. The Trane Company, itself a leading manufacturer of air conditioning equipment, Lexington, Kentucky. (See letter and data sheet attached, September 22, 1986).*
2. Holiday Foods, a Houston based supermarket chain. (See copy of article attached from Energy User News, April 1, 1985).*
3. Article attached, Today News, Lake Havasu City, Arizona, February 19, 1986.*

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*Retained in committee files.

Test units have recently been placed on some McDonalds and Pizza Hut restaurants. Data on these installations will be available soon.

We are interested in cooperating with your committee and any other instrumentalities of the Congress, the Environmental Protection Agency and private industry, such as may be appropriate to test this product relative to possible legislation and/or regulations based on the AMCS. We understand, for example, that the commanding general at Ft. Knox, Kentucky may be interested in participating in such testing.

We will be pleased to provide additional information such as you may require.

Respectfully submitted,